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THE ESTABLISHMENT OF A PRODUCTION-READY MANUFACTURING PROCESS UTILIZING THIN SILICON SUBSTRATES FOR SOLAR CELLS

FINAL REPORT
MOTOROLA REPORT NO. 2364/4
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OCTOBER 1980

JPL CONTRACT NO. 955328

PREPARED BY

R. A. PRYOR

MOTOROLA INC. SEMICONDUCTOR GROUP

5005 EAST McDOWELL ROAD

PHOENIX, ARIZONA 85008

THE JPL LOW-COST SOLAR ARRAY PROJECT IS SPONSORED BY THE U.S. DEPARTMENT OF ENERGY AND FORMS PART OF THE SOLAR PHOTOVOLTAIC CONVERSION PROGRAM TO INITIATE A MAJOR EFFORT TOWARD THE DEVELOPMENT OF LOW-COST SOLAR ARRAYS. THIS WORK WAS PERFORMED FOR THE JET PROPULSION LABORATORY, CALIFORNIA INSTITUTE OF TECHNOLOGY BY AGREEMENT BETWEEN NASA AND DOE.

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ABSTRACT

Three inch diameter Czochralski silicon substrates sliced directly to 5 mil, 8 mil, and 27 mil thicknesses with wire saw techniques were procured. Processing sequences incorporating either diffusion or ion implantation technologies were employed to produce n+p or n+pp+ solar cell structures. These cells were evaluated for performance, ease of fabrication, and cost effectiveness. It was determined that the use of 7 mil or even 4 mil wafers would provide near term cost reductions for solar cell manufacturers.

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1.0 SUMMARY

This contract was for the investigation, development, and characterization of methods for establishing production-ready manufacturing processes which utilize thin substrates for solar cells. The thin silicon substrates used for these investigations were sawed directly from three inch diameter ingots to thicknesses of 8 mils and 5 mils. Wafers sliced to 17 mils were employed as thick substrate reference samples. Sodium hydroxide etching techniques were used to prepare substrates with thicknesses ranging between the 5, 8, and 17 mil values. Wafers as thin as 3.9 mils were processed.

It was concluded, in general, that by choosing an appropriate processing sequence, exercising adequate care in handling, and providing sufficient start-up time to transcend the learning period, the thinnest wafers could be handled with yields only marginally smaller than those of the thickest wafers. Based on wafer slicing and processing yields anticipated for full scale production operations, it is cost effective to use even the thinnest wafers.

Several possible processing techniques were considered. A baseline process sequence using phosphorus diffusion was established for n+p type solar cells. This is perhaps the simplest process, corresponding to common industry practices today. It was determined that, in agreement with theory, cell performance (both voltage and current) decreases steadily as substrate thickness is decreased. Nevertheless, even for this simple cell structure it was shown that the thinner, 4 mil wafers would be most cost effective.

Numerous variations on the baseline process were considered, including the use of ion implantation to provide phosphorus and boron doping. It was determined that by using ion implantation processing, an advanced n+pp+ cell structure could be obtained while keeping wafer handling to a minimum. This is

important for maximizing yields for the very thin cells. Ion implantation techniques were shown to be capable of producing 7 mil cells with performance equalling or exceeding 17 mil cells. Based on these considerations, a pilot process sequence incorporating boron and phosphorus implants was established.

A total of 418 wafers, etched to various thickness values which spanned the range from 3.9 mils to 16.9 mils, was processed by the pilot sequence. The resulting cell test data indicate that solar cell voltage performance can be maintained regardless of cell thickness. However, for the process chosen it was found that short circuit current tended to decrease slowly for thicknesses below 7 mils. One difficulty encountered for the pilot process was that too few substrates were processed to complete the learning experience and establish a mature pilot line. This is particularly true for the development of routine handling techniques to insure against thin cell breakage. Nevertheless, the results of the pilot process tests reinforce the conclusions of thin cell cost effectiveness drawn from the baseline cell process.

It should be noted that this contract dealt primarily with the processing of thin substrates. Investigations were not performed with respect to slicing techniques. Thin silicon substrates for use in this effort were procured from a material supplier (Motorola) where they were produced by present day technology.

2.0 INTRODUCTION

Today, most commercially manufactured silicon solar cells are fabricated on ingot grown and sliced substrates. The ingot technology is primarily the Czochralski process. The ingots are sliced, typically with an ID circular saw, to form the substrate wafers. As-sawed wafers are chemically etched to remove sawing damage present on the surfaces.

Solar cell substrates prepared utilizing this ingot and sawing technology usually have thicknesses of 12 to 15 mils. This thickness is dictated by conventional substrate preparation yields and process handling considerations. Experience with ID sawing of crystals has shown that sawing yields decrease dramatically as the wafer thickness is decreased, primarily due to breakage during sawing. Handling of thinner substates during subsequent solar cell processing has also shown breakage problems for many current process sequences. This is not necessarily true for all processes, and is primarily a result of traditional rough and non-automated handling techniques.

Thicknesses of 12 to 15 mils are greater than needed for good solar cell performance. In general, the silicon substrate thickness should be comparable to the minority carrier diffusion length. For typical Czochralski substrates, diffusion lengths are on the order of 100 μm (4 mils) at most. Substrate thickness in excess of the diffusion length does not contribute substantially to cell performance but serves primarily as mechanical support. This extra support thickness contributes heavily to the cost of the completed solar cell since, today, silicon material is a major cost driver.

Further problems exist with ID sawing of ingots, namely, kerf loss and saw damage. For 3 inch diameter wafers, the kerf loss from ID sawing can be expected to be 12 mils or greater. Moreover, surface damage generated on the

wafer during sawing can range up to 1 mil deep. This surface damage must be removed to achieve an efficient solar cell. This means that approximately 14 mils of silicon thickness are lost to kerf and saw damage for each substrate cut. This amounts to a substantial cost for each solar cell, which is incurred prior to any solar cell processing. It would be very desirable to reduce both wafer thickness and kerf loss.

Several companies are implementing technologies for multiple-wire sawing of silicon ingots, routinely sawing thinner wafers with this technology than is possible with traditional ID sawing. These wafers have sawing damage layers only 6 to 8 μm deep on each surface, less than half the depth of damage in ID sawed wafers. Therefore, less etching is required to remove saw damage. Further, this can be done with a kerf loss of 7.5 to 8 mils. Such a slicing technology can be used to cut wafers at least as thin as 5 mils. Wafers this thin and with such a small kerf loss can have a major cost reduction effect on near-term solar cell manufacturing costs, if wafer preparation yields are acceptable and if solar cell fabrication processes are employed which minimize wafer handling and breakage.

The possibility of using wafers sawed at 5 mils with a 7.5 mil kerf makes the attainment of 1 m^2 of solar cells per kg of starting silicon a realistic short term proposition.

A square meter of silicon t mils thick weighs:

$$100 \text{ cm} \times 100 \text{ cm} \times t \text{ mils} \times \frac{10^{-3} \text{ in}}{\text{mil}} \times \frac{2.54 \text{ cm}}{\text{in}} \times \frac{2.33 \text{ gm}}{\text{cm}^3} = 59\ t \text{ gm}.$$

Allowing for kerf loss, the thinner (5 mil) wafers utilize 12.5 mils of crystal; this produces 32 wafers per cm of crystal. Hence, a square meter of silicon 5 mils thick utilizes 59 x 12.5 = 737.5 gm of silicon. This allows a budget of 262.5 gm out of the original 1000 gm of silicon for losses including crystal growing, slicing, and solar cell processing. Such a loss - 35% - is well within the bounds of practicality.

At current prices for polycrystalline silicon, about \$90/kg, the silicon cost for such a square meter of 5 mil thick silicon would be \$90. Assuming 14% encapsulated efficiency, which is now a generally accepted goal for single crystal silicon solar cell modules, one square meter of silicon would produce 140 watts. This results in a cost of \$90/kg / 140 watts/kg = 64¢/watt. At a projected intermediate polycrystalline silicon price of \$25/kg, the silicon content of a solar module will be less than 18¢/watt, which is well within the budget for a \$2/watt module. At a projected long term polycrystalline silicon price of \$7.50/kg, the silicon content of a solar module will be about 5¢/watt. This figure is not out of line for a 50¢/watt budget of about 15¢/watt each for the silicon substrate, wafer processing, and encapsulation.

The purpose of this contract was the investigation and characterization of solar cell fabrication processes which could utilize thin substrates for solar cells. The work proceeded on the assumption that thin substrates could be procured from a material supplier and, thus, did not include technical studies or development of sawing techniques. Three inch diameter wafers sliced by wire-saw techniques were purchased from the Motorola Semiconductor Group Materials Operation in three as-sawed thickness categories. 17 mils, 8 mils, and 5 mils. The 17 mil wafers were received in the as-sawed condition and used as control samples. The 8 mil wafers were received in two groups, one as-sawed and the other chem-etched to 7 mils to guarantee saw damage removal. The 5 mil wafers were received only after chem-etching to 4 mils.

These three thickness categories, when combined with varying degrees of surface etching immediately prior to cell processing, provided a range of substrates from today's conventional wafers to the thinnest wafers deemed practical with sliced-ingot technology. These substrates were used with various various cell processes to investigate the tradeoffs between processing

yields and cell performance as a function of wafer thickness. Processes based on both gaseous diffusion techniques and ion implantation techniques were studied. Both simple (front junction only) cell structures as well as devices incorporating back-surface enhancement layers were considered. In all cases, a primary criterion for process sequence choice was to minimize the required wafer handling so as to reduce thin cell breakage and increase yield.

Working with wafers which are substantially thinner than conventional substrates required a learning period, both in the development lab and on the production line. The number of cells processed over the duration of this contract was too small for an accurate statistical evaluation. It is believed, however, that sufficient quantities of material were processed to allow detection of all major problems attributed to thin cells and associated with the processes investigated. To this end, enough information has been developed to project the cost effects of introducing thin substrates into cell process lines in production quantities.

The following technical discussion details the specific investigations completed. In general, it has been demonstrated that the use of substrates thinner than today's conventional silicon wafers is an effective approach to reducing solar cell costs.

3.0 TECHNICAL DISCUSSION

3.1 THIN SUBSTRATE PROCUREMENT

Orders were placed with the Motorola Semiconductor Group Materials Operation for thin silicon substrate samples. Sample wafers were sliced from 3 inch diameter, p-type (boron doped) Czochralski ingots of approximately 1 Ω-cm resisitivity. The wafers were sawed to nominally 8 mil and 5 mil thicknesses using a multiple-wire saw. After sawing, most samples were chemically etched to remove approximately one-half mil from each side to eliminate residual sawing damage. Hence, final thickness values were 7 mils and 4 mils. A number of the 8 mil as-sawed substrates were delivered before etching. These substrates were used for the later "production process" lots as well as for studies on saw damage removal.

In addition to the thin substrates, wire-sawed (and edge-rounded) wafers approximately 17 mils thick were obtained. These wafers were used as control samples to approximate the performance of solar cells of conventional thickness.

The substrates thus procured for testing had excellent statistical distributions of wafer thickness and wafer resistivity. Sample measurements from the group of 8 mil as-cut wafers and the group of 4 mil sawed and etched wafers are given in Tables 1, 2, and 3.

Tables 1 and 2 show thickness measurements made at five positions on each wafer tested. The five positions include a center position and four edge positions as shown in Figure 1. The average for all thickness measurements on the nominally 8 mil as-cut wafers is 8.24 mils (standard deviation is 0.18 mils). The average for the nominally 4 mil sawed and etched wafers is 4.27 mils (standard deviation is 0.10 mils).

TABLE 1

Test wafer thickness measurements for nominal 8 mil, as-cut wafers.

Test Wafer Number	Thickness In Mils				
	Center Position	Edge Positions			
1	8.10	8.00	7.93	8.18	8.08
2	8.21	8.12	8.33	8.21	8.39
3	8.14	8.05	8.29	8.19	8.17
4	8.25	8.13	8.38	8.58	8.13
5	8.50	8.63	8.54	8.53	8.68
6	8.03	8.12	8.00	8.00	7.99
7	8.19	8.08	8.02	8.23	8.29
8	8.22	8.12	8.15	8.19	8.15
9	8.42	8.42	8.40	8.28	8.27
10	8.39	8.52	8.41	8.25	8.24

	Center Readings	All Readings
Mean	8.25	8.24
Standard Deviation	0.15	0.18
% Standard Deviation	1.8%	2.2%

TABLE 2

Test wafer thickness measurements for nominal 4 mil, sawed and etched wafers.

Test Wafer Number	Thickness In Mils				
	Center Position	Edge Positions			
1	4.37	4.30	4.41	4.12	4.41
2	4.33	4.20	4.25	4.21	4.32
3	4.32	4.35	4.10	4.32	4.05
4	4.28	4.15	4.41	4.08	4.18
5	4.39	4.28	4.39	4.28	4.37
6	4.35	4.38	4.36	4.30	4.30
7	4.38	4.28	4.27	4.40	4.23
8	4.34	4.20	4.30	4.33	4.21
9	4.32	4.24	4.38	4.18	4.26
10	4.41	4.30	4.44	4.48	4.49
11	4.25	4.10	4.26	4.19	4.11
12	4.20	4.12	4.28	4.11	4.10
13	4.31	4.51	4.12	4.17	4.19
14	4.37	4.22	4.18	4.39	4.12
15	4.28	4.31	4.22	4.11	4.19
16	4.32	4.33	4.23	4.21	4.27
17	4.37	4.47	4.24	4.28	4.27
18	4.41	4.19	4.47	4.05	4.49
19	4.36	4.25	4.38	4.20	4.29
20	4.22	4.09	4.14	4.23	4.28
21	4.37	4.35	4.27	4.32	4.21
22	4.31	4.12	4.22	4.26	4.18
23	4.38	4.40	4.19	4.24	4.23
24	4.35	4.21	4.42	4.18	4.26
25	4.36	4.31	4.43	4.12	4.31

	Center Readings	All Readings
Mean	4.33	4.27
Standard Deviation	0.05	0.10
% Standard Deviation	1.2%	2.3%

TABLE 3

Test wafer resistivity, measured at wafer center with four point probe.

Test Wafer Number	Resistivity in Ω cm	
	8 mil Wafers	4 mil Wafers
1	1.29	1.30
2	1.31	1.35
3	1.31	1.18
4	1.23	1.13
5	1.38	1.21
6	1.25	1.21
7	1.34	1.15
8	1.20	1.14
9	1.24	1.16
10	1.19	1.17
11	1.22	1.16
12	1.24	1.24
13	1.23	1.30
14	1.21	1.23
15	1.06	1.25
16	1.10	1.15
17	1.07	1.16
18	1.22	1.31
19	1.23	1.32
20	1.15	1.32
21	1.06	1.23
22	1.12	1.20
23	1.12	1.17
24	1.08	1.21
25	1.27	1.17
Mean	1.20	1.22
Standard Deviation	0.09	0.07
% Standard Deviation	7.5%	5.4%

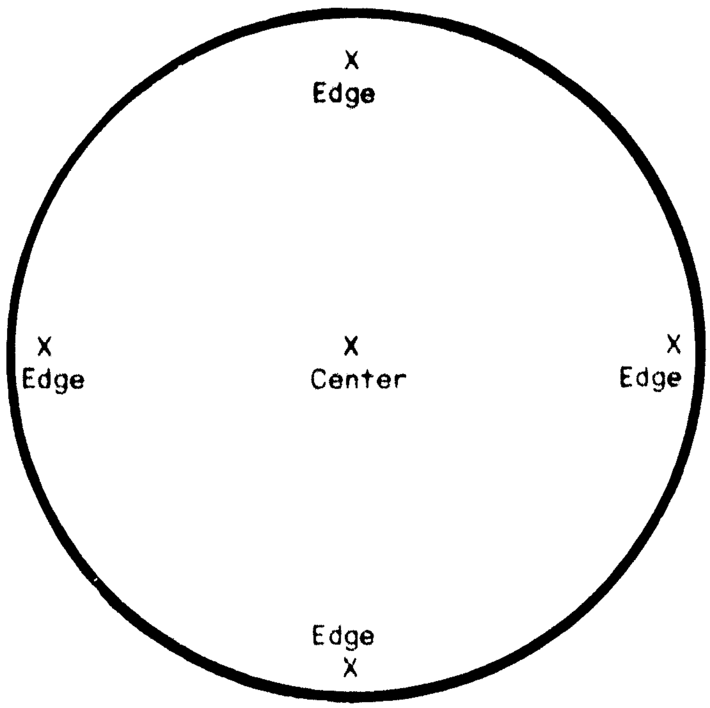

Figure 1: Diagram showing positions where thickness measurements were made on sample wafers.

Table 3 shows resistivity measurements made at the center of each wafer tested. The average thicknesses stated above were assumed for calculating wafer resistivity. Wafers of either thickness have resistivities averaging near 1.2 Ω-cm.

These thin substrates represent what must be considered to be feasibility trials in sawing thin wafers. The substrates sawed directly to 8 mils are among the first to be produced by Motorola, and those sawed directly to 5 mils are the first. The actual wafering yields obtained with these initial attempts are good, but these yields are expected to improve rapidly as experience is accumulated. It is anticipated that a yield of 85% is readily attainable for 8 mil wafer production. This means that, of the maximum number of available wafers per inch of crystal, 0.85 times this number will be achieved. The maximum number of wafers per inch is determined by dividing one inch by the sum of the sawed wafer thickness in inches and the kerf loss. For the process used to saw wafers for this contract, the kerf is 0.0078 inch. At 85% yield, an inch of crystal should yield 63.3 wafers which are 8 mils thick.

The actual data for two of the wafer procurements made for this contract are given below. For the first procurement, wafers were cut to nominally 8 mils. The actual measured thickness is 8.25 mils. A total of 14.0 inches of crystal was sent to be sawed and 438 wafers were delivered. From 14.0 inches, the maximum number of wafers available is 872 wafers (62.3 wafers/inch). Thus the yield from the initial attempt was 50.2%. This is equivalent to 31.3 wafers/inch.

For the second procurement, wafers were cut to nominally 5 mils. The actual thickness is 5.33 mils. A total of 11.1 inches of crystal was sent to be sawed and 296 wafers were obtained. This represents a yield of 35.0% since 26.7 wafers/inch were obtained while the maximum available was 76.1 wafers/inch.

3.2 INITIAL WAFERING COST ANALYSIS

During the work on this contract, no substantial difficulties were encountered in utilizing the same processing sequence for wafer thicknesses ranging between 17 mils and 4 mils. This is due, primarily, to the nature of the process sequences studied. While initial experiments, as discussed in later sections of this report, resulted in lower processing yields for the thinnest wafers, this is deemed to be due to the learning experience and is not considered to be a future impediment. No reason can be envisioned at this time for assuming that the thinnest wafers must result in lower yields in a production process. Additionally, it is expected that down to a wafer thinness of 4 mils there whould be no loss in solar cell power conversion efficiency if the proper cell design features can be employed.

Accordingly, the principal cost tradeoffs occur in the wafer slicing process. If thin wafers can be sliced with reasonable yields, more substrate area can be obtained per kilogram of silicon ingot, thus effecting a cost savings.

An initial wafering cost analysis has been performed using the JPL/IPEG (Interim Price Estimation Guidelines) formulas. The IPEG methodology is thoroughly described in JPL Document No. 5101-33. IPEG calculations have been made to estimate the price per watt for substrates of three separate thicknesses: 13 mils, 8 mils, and 5 mils. These thicknesses represent a standard reference thickness plus the two as-cut thicknesses actually being used for this contract. Only present-day, three inch diameter wafers are considered.

An important part of this analysis is use of a wire-saw process for slicing standard Czochralski silicon ingots. The basic saw prameters, listed in Table 4, are obtained both from reported data and in-house experience. These parameters are used to compute the required EQPT, SQFT, DLAB, MATS, and UTIL quantities for the IPEG equation. In addition, a cost of $13.79 per square meter of cutting area

TABLE 4: MULTIPLE-WIRE SAW PARAMETERS

Silicon ingot diameter	3 inches (7.62 cm)
Ingot length per cut	4 inches (10.16 cm)
Kerf loss	.0078 inch
Set-up time	40 min.
Cutting time	180 min.
Total cycle time	220 min.
Cost per saw (1977)	$30,000
Machines per operator	10
Maintenance Mechanics	0.48/machine
Electricity usage	500 watts
Raw (domestic) water usage	1 gal/min.
Manufacturing space required	40 sq. ft./machine
Projected slicing yields	
13 mil wafers	93%
8 mil wafers	85%
5 mil wafers	80%

is assessed to cover expendable supplies such as abrasive, wire, wire guides, and other miscellaneous items.

The cost of the 3 inch diameter Czochralski ingot used as the slicing input material is assumed to be $250 per kilogram. This is taken from a 1978 price calculation based on $60 per kilogram poly-silicon which was reported by SILTEC at the ninth JPL Project Integration Meeting.

The price of a wafer obtained from this slicing process depends strongly on sawing yields and throughput. Since the direct slicing of 5 mil wafers or 8 mil wafers is not yet a production process, some reasonable assumptions must be made concerning yields. Actual yields in a production process are expected to be considerably greater than the 50.2% and 35.0% values discussed in Section 3.1. Slicing yields for 8 mil wafers should quickly approuch 85%, a reasonably conservative value. Anticipating that 5 mil slicing won't quite be capable of duplicating the yield for 8 mil slicing, it is assumed that yields for 5 mil slices will approach a value of 80%. Standard 13 mil wafers should be sliced with at least 93% yields. Hence, for the purposes of this cost analysis, it is assumed that 13 mil wafers are sliced with 93% yield, 8 mil with 85% yield, and 5 mil with 80% yield.

The maximum allowable throughput values for each wafer thickness must be weighted by the yields assumed above. To determine throughput per saw, note from Table 4 that one 4 inch long crystal is sliced in each 220 minute period. This 4 inch length, divided by the sum of the slice thickness plus .0078 inch kerf, gives the maximum number of wafers produced in 220 minutes. Hence the maximum throughput rates are as follows:

13 mil	0.874 waf/min. or 52.44 waf/hr.
8 mil	1.151 waf/min. or 69.06 waf/hr.
5 mil	1.420 waf/min. or 85.20 waf/hr.

If these maximum rates are weighted by the assumed yields, then the assumed throughputs used for IPEG calculations are as follows:

13 mil	52.44 x 0.93 = 48.77 waf/hr.
8 mil	69.06 x 0.85 = 58.70 waf/hr.
5 mil	85.20 x 0.80 = 68.16 waf/hr.

These throughput values will be used to determine the floor space, number of machines, number of labor personnel, utility usage, and materials requirements associated with slicing for a factory operating at approximately one megawatt per year output.

It is assumed that a 3 inch diameter solar cell power conversion efficiency of 14% is obtained. Then a throughput of 190 wafers/hour is equivalent to 999,146 watts/year. Thus all of the cost calculations will be based on a throughput of 190 waf/hr.

As an example calculation, consider floor space. A manufacturing space of 40 sq. ft. per machine is required, as noted in Table 4. For the three cases of 13, 8, and 5 mil slices, 190 waf/hr. requres more than one machine, since the yielded throughputs per machine are less than this. To determine the floor space requirement, the desired throughput (190 waf/hr) is divided by the yielded throughput for each case and then multiplied by 40 sq. ft. Thus, the floor space requirement for each case is as follows:

$$\underline{\text{13 mil}} \quad \text{SQFT} = \frac{190 \text{ waf/hr}}{48.77 \text{ waf/hr}} \times 40 \text{ sq. ft.} = 155.83 \text{ sq. ft.}$$

$$\underline{\text{8 mil}} \quad \text{SQFT} = \frac{190 \text{ waf/hr}}{58.70 \text{ waf/hr}} \times 40 \text{ sq. ft.} = 129.47 \text{ sq. ft.}$$

$$\underline{\text{5 mil}} \quad \text{SQFT} = \frac{190 \text{ waf/hr}}{68.16 \text{ waf/hr}} \times 40 \text{ sq. ft.} = 111.50 \text{ sq. ft.}$$

Similar weightings are performed for the cost of materials (MATS), the cost of labor (DLAB), the cost of capital equipment (EQPT), and the cost of utilities (UTIL). The total values so obtained for each category are listed in Table 5.

TABLE 5: IPEG COMPONENT COST VALUES FOR SLICING 190 WAFERS/HOUR FOR A TOTAL OF ONE YEAR.

SLICE THICKNESS (mils)	EQPT ($)	SQFT (sq. ft.)	DLAB ($)	MATS ($)	UTIL ($)
13	102,083	156	70,060	2,031,104	1,036
8	84,814	129	58,208	1,711,955	861
5	73,043	112	50,130	1,494,300	741

NOTE: This represents direct costs for one year (approximately one megawatt output). Dollars are in 1975 values. Materials costs include the cost of Cz silicon ingot which is sliced.

Using the values in Table 5, the IPEG price equation is applied. In this equation, total price P = 0.489 EQPT + 96.9 SQFT + 2.133 DLAB + 1.255 MATS + 1.255 UTIL. This equation gives an estimate of the total selling price in dollars. A more convenient set of units is dollars per watt, obtained by dividing the total price equation by the total number of watts produced for that price (in this case 999,146 watts, assuming 190 waf/hr for one year at 14% efficiency per wafer). The total IPEG price and its component parts are given in 1975 dollars per watt in Table 6. Hence the price of sliced substrates should be $2.767, $2.330, and $2.031 for 13, 8, and 5 mil thicknesses, respectively, per watt.

Over two thirds of each of the total prices resulting from this cost analysis are directly attributable to the cost of the Cz ingot starting material. If that portion of the total price which is due to ingot costs is subtracted from the total price, the effective add-on price for the slicing process is obtained. This is shown in Table 7.

The total prices for sliced substrates given in Tables 6 and 7 are in reasonable agreement with near-term price allocation guidelines established by JPL. A table of near-term guidelines presented at the Ninth JPL Project Integration Meeting is reproduced in Table 8. The expected price of $2.34 per watt for the 1980 timeframe when polysilicon is priced at $60 per kilogram is very close to the predicted prices of today's wire-wawed 13, 8, and 5 mil substrates resulting from the IPEG analysis above.

3.3 INITIAL EXPERIMENTAL LOTS

Three inch diameter Czochralski wafers sawed to thicknesses of 17 mils, 8 mils, and 5 mils were prepared by the Motorola Semiconductor Group Materials Operation. A multiple-wire sawing technology was employed. Some of the 8 mil wafers and all of the 5 mil wafers were further prepared by chemically etching 0.5 mil of silicon from each side to guarantee removal of sawing damage. Statistical measurements on this material were reported in

TABLE 6: IPEG COMPONENT PRICES AND TOTAL PRICE OF SLICED SUBSTRATE IN 1975 DOLLARS PER WATT.

SLICE THICKNESS (mils)	0.498 EQPT	96.9 SQFT	2.133 DLAB	1.255 MATS	1.255 UTIL	TOTAL PRICE (\$/W)
13	.050	.015	.150	2.551	.001	2.767
8	.042	.013	.124	2.150	.001	2.330
5	.035	.011	.107	1.877	.001	2.031

NOTE: This represents selling prices for substrates after slicing including the cost of single cyrstal Cz ingots used in slicing. A 14% cell efficiency is assumed and 3 inch diamter wafers are used.

TABLE 7: DIVISION OF TOTAL PRICE INTO THAT PORTION DUE TO SILICON SINGLE CRYSTAL INGOT COST AND THAT PORTION ESSENTIALLY DUE TO ADD-ON PRICE OF SLICING. 1975 DOLLARS.

SLICE THICKNESS (mils)	TOTAL PRICE ($/W)	PRICE DUE TO Cz INGOT COST ($/W)	EFFECTIVE SLICING ADD-ON PRICE ($/W)
13	2.767	1.940	0.827
8	2.330	1.612	0.718
5	2.031	1.388	0.643

See note of Table 6

TABLE 8: INGOT TECHNOLOGY PRICE ALLOCATION GUIDELINES FROM THE PROCEEDINGS OF THE NINTH JPL PROJECT INTEGRATION MEETING, APRIL 1978. 1975 DOLLARS.

YEAR	1978	1980	1982
CELL EFFICIENCY REQUIREMENT	11.5%	13%	14%
POLY SILICON COST	$65/kg	$60/kg	$40/kg
SLICED SUBSTRATE PRICE	$3.75/W	$2.34/W	$1.19/W
ENCAPSULATED CELL PRICE	$7.00/W	$4.00/W	$2.00/W

Section 3.1 of this report. A number of these wafers, along with some control wafers produced by Wacker, were used to establish the first six test lots for thin cell fabrication. The cells produced in these lots provided a baseline for judging cell performance and processing improvements directed toward incorporating thin substrates into production processing.

Each test lot was started with 24 wafers per lot. This number allows a space position for a test wafer in the standard carriers and diffusion boats which hold 25 wafers. Each of the six test lots is described in the following paragraphs. Each starting wafer in each of the six lots has been measured to determine wafer resistivity and thickness at the wafer center. All wafers are Czochralski material.

Lot A1 is a control. It contains wafers produced by Wacker which are chemically etched on the back and polished on the front. The average wafer resistivity is 2.34 Ω-cm (σ = 0.10 Ω-cm) and the average center thickness is 14.28 mils (σ = 0.21 mils).

Lot A2 contains wafers from crystals grown at Motorola; they are in the as-cut condition and are edge rounded. The average wafer resistivity is 1.01 Ω-cm (σ = 0.11 Ω-cm) and the average thickness at the center is 17.74 mils (σ = 0.19 mils).

Lot A3 is a lot of thin, as-cut wafers grown and cut at Motorola. These wafers are not edge rounded. The average wafer resistivity is 1.30 Ω-cm (σ = 0.02 Ω-cm) and the average center thickness is 8.24 mils (σ = 0.20 mils).

A4 is a lot of thin wafers sliced at Motorola to approximately 5 mils and then chemically thinned to eliminate saw damage. Average wafer resistivity is 1.20 Ω-cm (σ = 0.04 Ω-cm) and the average center thickness is 4.39 mils (σ = 0.05 mils).

A5 is a lot of thin wafers sliced at Motorola to approximately 8 mils, edge rounded, and then chemically etched. The average wafer

resistivity is 1.44 Ω-cm (σ = 0.19 Ω-cm) and the average center thickness is 7.22 mils (σ = 0.11 mils).

Lot A6 is identical to lot A5 in starting condition. The average wafer rosisitivity is 1.51 Ω-cm (σ = 0.19 Ω-cm) and the average center thickness is 7.09 mils (σ = 0.09 mils).

Detailed tabulations of resistivity and starting thickness measurements for each lot will be presented as part of the data in Section 3.5.3.

With the exception of surface texturing, all six lots were processed through the same junction formation, antireflection coating, and metallization steps. The wafers in lots A1, A2, A3, A4, and A5 have been textured on both sides using the standard Motorola texture etch process. As a result, lots A1 and A2 have textured peaks with a nominal height of 7 microns, lot A3 has textured peaks nominally 6.5 microns high, and lots A4 and A5 have textured peaks nominally 5 microns high.

Each wafer in each lot was measured after texturing to determine wafer thickness loss. The average "peak-to-peak" thickness loss from before to after texturing ranged from 4.8 microns to 7.6 microns. Thickness measurements were performed with a stage micrometer, so measurements with textured surfaces reflect the distance from textured peaks on one side to the tips of textured peaks on the other side. Thickness data after texture are also tabulated in Section 3.5.3.

Lot A6 was not textured and has been retained in the smooth, chemically etched surface condition.

Table 9 summarizes the substrate characteristics for each of the six test lots.

TABLE 9: SUMMARY OF THE COMPOSITION AND SUBSTRATE CHARACTERISTICS FOR TEST LOTS A1 THROUGH A6.

LOT NUMBER	LOT FUNCTION	AVERAGE STARTING THICKNESS (mils)	STARTING WAFER CONDITION	PROCESSED SURFACE CONDITION	LOT RESISTIVITY RANGE (Ω-cm)	WAFER MANUFACTURER
A2	control	17.7	as-sawed*, edge-rounded	textured	0.87-1.12	Motorola
A3	test	8.2	as-sawed*	textured	1.26-1.33	Motorola
A5	test	7.2	chem-etched, edge-rounded	textured	1.18-1.73	Motorola
A4	test	4.4	chem-etched	textured	1.17-1.37	Motorola
A6	test	7.1	chem-etched, edge-rounded	as-started	1.15-1.70	Motorola
A1	control	14.3	polished front, chem-smoothed back	textured	2.12-2.49	Wacker

*as-sawed using multiple wire saw technology

3.4 INITIAL PROCESS SEQUENCE

The initial six test lots of thin substrate solar cells were processed with the following process sequence:

1. Start with sawed, or sawed and etched, wafers.
2. Clean wafers in hot piranha solution (a mixture of sulfuric acid and hydrogen peroxide), rinse, etch in dilute HF solution, rinse.
3. Texture etch both sides of wafers and rinse (excluding lot A6).
4. Dry wafers using Freon vapor "degreaser" technique.
5. Plasma oxidation/clean ("ashing").
6. PH_3 diffusion, both sides, at 900°C for approximately 18 minutes.
7. Strip phosphorus glass in HF and rinse.
8. Dry wafers using Freon vapor "degreaser" technique.
9. Mesa etch front perimeter and etch back to remove phosphorus layer. This is done with a standard photoresist procedure to protect the desired junction from the silicon etch (nitric-hydrofluoric-acetic acid mixture).
10. Plasma oxidation/clean.
11. LPCVD Si_3N_4 deposition.
12. Etch front metal pattern, stripping back surface Si_3N_4 layer.
13. Metallize.

In step 13, to eliminate initial concern for stress in using a solder coating process for the metal contact, a plated palladium-silver metallization system was used for lots A1 through A6.

In step 4 of the process sequence listed above, wafers are dried in the following manner. After rinsing, a carrier of wet wafers is placed in a container of isopropal alcohol which displaces and mixes with the water on the wafer surface. The carrier is then placed in the hot vapor section of a Freon vapor degreaser. The hot Freon vapor condenses on the colder wafer

surfaces and drips off the wafers to the liquid sump below, carrying any particulate residue away. As the carrier of wafers is withdrawn from the vapor, the Freon remaining on the wafer surface evaporates, leaving the wafers dry. This drying process was originally chosen because it provides a very gentle method for drying the thin substrates. However, it has since been determined with other experiments that conventional centrifugal spin-drying can be used, even for the 4 mil substrates, without substantial risk of breakage.

In step 11 of the process sequence, LPCVD silicon nitride deposition refers to a low pressure chemical vapor deposition process whereby a uniform Si_3N_4 film is deposited on both sides of the solar cell substrate at pressures below atmospheric pressure. The nitride film thickness is such as to serve both as a metal plating mask and as a front surface antireflection coating. This process provides uniformity and reliability of Si_3N_4 coating with excellent throughput.

Plasma oxidations were introduced in steps 5 and 10 as the first effort to eliminate some of the wafer handling involved in using wet chemical cleans and rinses prior to high temperature furnace operations. Using the dry plasma process requires less handling and is more gentle with respect to breakage of very thin silicon substrates.

Pertinent data were taken for each wafer in lots A1 through A6 after each major step in the process sequence. Junction sheet resistances were measured for the phosphorus diffused layer after completing step 8. Photogeneration current was measured after step 9 by using a diode curve-tracer to observe the solar cell reverse-biased characteristic I-V curve under simulated AM1 illumination. The illumination was provided by a quartz-halogen lamp source and calibrated with a reference cell fabricated by JPL.

These in-process data are given in the detailed tabulations to be found in Section 3.5.3. Wafer loss through in-process breakage was also recorded and this information was used to calculate cumulative yields after major process steps.

3.5 INITIAL EXPERIMENTAL RESULTS

3.5.1 BASELINE CELL STRUCTURE

As a result of the process sequence described in Section 3.4, the baseline solar cell structure is a very basic n-on-p configuration. This is similar to what might be used if one were choosing a structure for the least expensive fabrication costs with today's technology.

Of the six lots discussed in this report, five consisted of wafers which were textured, both front and back, at the onset of processing. One lot was not textured, but was chemically etched to smooth the as-sawed surface.

The n-type front surface junction layer was formed with a phosphorus diffusion (from a PH_3 source) followed by a mesa etch process. The mesa etch process strips the unwanted diffused layer from the back of the substrate and from a ring around the edge of the cell front. Those areas which have been etched to remove phosphorus are smoothed considerably compared to the original sharp-edged textured surface but still retain tetrahedral shapes. The resulting p-n junction area is 43.3 cm^2. The average junction depth for lots A1 through A6 is near 0.6 µm. No back surface enhancement diffusion (p+ layer) or back surface field (BSF) was employed for these lots.

The completed solar cells have an antireflection coating of silicon nitride (Si_3N_4). Average Si_3N_4 coating thickness for the six test lots is 744Å.

A metal plating mask is formed with the Si_3N_4 by stripping the back surface of the wafer and patterning the front with a metal grid pattern. Thus, the completed cells have metal totally covering the back surface. The front surface grid shadows approximately 8% of the p-n junction area.

As previously stated, the metallization used for lots A1 through A6 consists of a palladium-palladium silicide contact layer and a silver conducting layer. This system was chosen because it was available and because the 4 mil substrates could be safely plated without concern for breakage likely to be encountered if a solder-dip process were chosen. Unfortunately, the front surface grid pattern used is optimized for a soldered metallization. The amount of shadowing could be reduced if the pattern were optimized for silver instead. With the pattern used and the silver conductor, the total series resistance of the cell is typically about 5 milliohms. This corresponds to a voltage loss of about 6 mV at an output current of 1200 mA.

3.5.2 LOT DATA SUMMARY

Important parameters and experimental results for the baseline cell test lots are summarized in Table 10. Where items are labeled average they are the mean value of measurements taken on all the cells in a given lot.

The as-processed wafer thickness is the measured "peak-to-peak" wafer thickness after texturing except for lot A6, which is not textured. This measurement was discussed in Section 3.3. The textured surface peak size is an estimate (by optical microscopy) of the largest typical distance from the base of the silicon surface tetrahedra to the peak.

The open circuit voltage (V_{OC}) and short circuit current (I_{SC}) values represent measurements on the completed solar cells. V_{OC} measurements were

TABLE 10: SUMMARY OF IMPORTANT LOT PARAMETERS AND EXPERIMENTAL RESULTS.

LOT NUMBER	AVERAGE WAFER THICKNESS AS-PROCESSED (mils)	TEXTURED SURFACE PEAK SIZE (μm)	AVERAGE WAFER RESISTIVITY (Ω-cm)	AVERAGE V_{OC} (mV)	AVERAGE I_{SC} (mA)	REPRESENTATIVE P_{max} (mW)	1st ATTEMPT PROCESSING YIELD (%)
A2	17.44	7	1.01	602	1306	629	100
A3	7.95	6.5	1.30	586	1251	580	91.7
A5	7.03	5	1.44	592	1286	595	95.8
A4	4.18	5	1.20	578	1185	550	66.7
A6	7.09	not textured	1.51	586	1234	569	91.7
A1	14.09	7	2.34	576	1284	586	83.3

made with a digital voltmeter and I_{SC} values were read from a curve-tracer display. All such measurements were made under tungsten-quartz-halogen lamp (type ENH) illumination set to an insolation of 100 mW/cm^2 by a JPL-calibrated reference cell (No. MO-04).

The maximum power (P_{max}) data represent values taken from current-voltage characteristic curve plots which will be given in Section 3.5.3.

Processing yield is simply the number of completed solar cells left intact per lot divided by 24, the number of wafers started per lot. The yield loss is strictly a result of wafer breakage. Two notes of caution must be given for interpreting the yield numbers. First, these lots represent the first attempt to process substrates of such thinness and must be expected to suffer somewhat from inexperience. As more experience is obtained and as processing is altered to accommodate the special nature of thin substrates, yield will be improved. Second, the wafers in these lots were subjected to an extra measure of prodding and probing by trying to accumulate substantial amounts of in-process data. This increases the amount of handling and increases the chance for initiating fractures. Such data accumulation would not ordinarily be done for routine cell production.

3.5.3 DETAILED DATA PRESENTATION

The data summarized in Table 10 are given in detail at the end of this section in Tables 11 through 16 and Figures 2 through 7 for lots A1 through A6, respectively. In addition, Tables 11 through 16 list measurements of starting substrate thickness, phosphorus diffused layer sheet resistance, and solar cell photo-generation current obtained before antireflection coating and metallization are applied. For each set of data tabulated, the statistical mean, standard deviation, and percent standard deviation are given. Percent

TABLE 11: Wafer data for test lot no. A1

WAFER NUMBER	STARTING THICKNESS (mils)	WAFER RESISTIVITY (Ω-cm)	THICKNESS AFTER TEXTURE (mils)	JUNCTION SHEET RESISTANCE (Ω/□)	BARE SURFACE GENERATION CURRENT (mA)	COMPLETED CELL SHORT CIRCUIT CURRENT I_{SC} (mA)	COMPLETED CELL OPEN CIRCUIT VOLTAGE V_{OC} (mV)
1	13.91	2.47	13.93	33.2	1230	1300	579
2	14.15	2.34	13.94	33.9	1240	1300	575
3	14.06	2.27	13.82	31.9	1230	1300	577
4	14.40	2.41	14.25	34.0	1240	1280	575
5	13.97	2.39	13.81	---	---	---	---
6	14.33	2.42	14.12	31.0	1230	1280	576
7	14.43	2.49	14.27	34.8	1230	1280	575
8	14.22	2.30	14.10	31.6	1230	1280	577
9	14.48	2.29	14.31	32.3	1220	1280	577
10	14.50	2.44	14.37	35.6	1220	1280	574
11	14.42	2.30	14.21	31.6	1220	1280	576
12	14.07	2.37	13.90	29.0	1230	1280	575
13	14.47	2.33	14.29	33.6	1210	1280	574
14	14.23	2.44	14.10	31.0	1220	1270	574
15	14.55	2.48	14.40	31.6	1230	1270	573
16	14.43	2.17	14.26	31.1	1220	1280	577
17	14.16	2.29	14.00	33.2	1220	1280	573
18	14.68	2.36	14.51	30.2	1230	1300	577
19	14.20	2.12	14.05	31.5	1230	---	---
20	13.93	2.29	13.74	31.7	1240	1280	575
21	14.41	2.36	13.85	29.5	1240	1290	577
22	14.18	2.37	13.90	30.1	1250	---	---
23	14.38	2.38	14.21	31.3	1250	---	---
24	14.04	2.19	13.84	30.2	1270	1290	574
MEAN STD. DEV. % STD. DEV.	14.28 0.21 1.5%	2.34 0.10 4.1%	14.09 0.22 1.5%	32.0 1.7 5.3%	1232 13 1.1%	1284 9 0.7%	576 2 0.3%
CUMULATIVE YIELD	N.A.	N.A	100%	95.8%	95.8%	---	83.3%

TABLE 12: Wafer data for test lot no. A2

WAFER NUMBER	STARTING THICKNESS (mils)	WAFER RESISTIVITY (Ω-cm)	THICKNESS AFTER TEXTURE (mils)	JUNCTION SHEET RESISTANCE (Ω/□)	BARE SURFACE GENERATION CURRENT (mA)	COMPLETED CELL SHORT CIRCUIT CURRENT I_{SC} (mA)	COMPLETED CELL OPEN CIRCUIT VOLTAGE V_{OC} (mV)
1	17.82	0.89	17.28	32.4	1220	1290	607
2	17.68	0.88	17.22	32.0	1210	1300	605
3	17.82	0.87	17.41	33.5	1200	1310	605
4	17.67	0.88	17.35	33.7	1200	1310	605
5	17.58	0.89	17.32	32.9	1200	1300	603
6	17.63	0.87	17.39	33.9	1190	1300	603
7	17.51	0.88	17.27	31.9	1190	1300	603
8	17.50	0.88	17.28	34.6	1190	1310	605
9	17.68	0.89	17.28	32.0	1180	1300	602
10	17.89	0.88	17.43	34.0	1200	1300	604
11	17.77	1.09	17.55	31.1	1200	1300	599
12	17.96	1.12	17.70	32.0	1200	1310	600
13	18.10	1.11	17.68	34.0	1220	1320	601
14	17.79	1.12	17.48	31.5	1200	1320	600
15	17.58	1.09	17.35	31.3	1200	1310	600
16	17.94	1.10	17.71	32.7	1200	1310	599
17	18.07	1.10	17.79	29.8	1190	1300	599
18	17.65	1.08	17.43	30.3	1200	1300	598
19	17.59	1.10	17.38	31.0	1210	1310	600
20	17.62	1.04	17.35	28.4	1210	1310	600
21	17.59	1.09	17.37	31.7	1200	1310	600
22	17.60	1.08	17.35	28.9	1200	1310	601
23	17.70	1.12	17.38	28.6	1220	1310	600
24	18.13	1.10	17.75	28.0	1200	1310	599
MEAN STD. DEV. % STD. DEV.	17.74 0.19 1.1%	1.01 0.11 10.9%	17.44 0.17 1.0%	31.8 1.8 5.6%	1201 10 0.8%	1306 7 0.5%	602 3 0.4%
CUMULATIVE YIELD	N.A.	N.A.	100%	100%	100%	---	100%

TABLE 13: Wafer data for test lot no. A3

WAFER NUMBER	STARTING THICKNESS (mils)	WAFER RESISTIVITY (Ω-cm)	THICKNESS AFTER TEXTURE (mils)	JUNCTION SHEET RESISTANCE (Ω/□)	BARE SURFACE GENERATION CURRENT (mA)	COMPLETED CELL SHORT CIRCUIT CURRENT I_{SC} (mA)	COMPLETED CELL OPEN CIRCUIT VOLTAGE V_{OC} (mV)
1	8.83	1.28	8.45	54.6	1240	---	---
2	8.06	1.27	7.81	46.5	1240	1270	588
3	8.31	1.26	8.05	40.3	1230	1250	586
4	8.60	1.28	8.28	---	---	---	---
5	8.31	1.30	8.03	56.4	1240	1250	586
6	8.08	1.30	7.82	63.4	1240	1220	579
7	8.30	1.26	8.05	54.3	1240	1260	586
8	8.50	1.28	8.20	64.6	1220	1280	588
9	8.22	1.30	7.92	55.8	1230	1260	586
10	8.03	1.32	7.76	46.5	1230	1250	585
11	8.09	1.32	7.82	52.8	1230	1260	586
12	8.08	1.31	7.80	52.0	1230	1250	586
13	8.14	1.32	7.89	50.5	1220	1250	585
14	8.20	1.30	7.95	48.7	1240	1250	586
15	8.28	1.27	8.00	47.2	1240	1250	586
16	8.31	1.31	8.03	44.6	1240	1240	586
17	8.42	1.31	7.99	54.9	1240	1240	585
18	8.12	1.33	7.35	45.8	1230	1260	587
19	8.06	1.32	7.80	44.0	1240	1240	577
20	8.08	1.31	7.81	45.1	1230	1250	585
21	8.25	1.31	7.98	40.3	1230	1250	586
22	8.12	1.31	7.90	40.0	1230	1250	586
23	8.06	1.33	7.75	37.6	1240	1250	586
24	8.25	1.29	7.97	37.1	1210	1240	585
MEAN	8.24	1.30	7.95	49.4	1233	1251	586
STD. DEV.	0.20	0.02	0.17	7.3	8	12	2
% STD. DEV.	2.4%	1.6%	2.1%	14.8%	0.7%	1.0%	0.3%
CUMULATIVE YIELD	N.A.	N.A.	100%	95.8%	95.8%	---	91.7%

TABLE 14: Wafer data for test lot no. A4							
WAFER NUMBER	STARTING THICKNESS (mils)	WAFER RESISTIVITY (Ω-cm)	THICKNESS AFTER TEXTURE (mils)	JUNCTION SHEET RESISTANCE (Ω/□)	BARE SURFACE GENERATION CURRENT (mA)	COMPLETED CELL SHORT CIRCUIT CURRENT I_{SC} (mA)	COMPLETED CELL OPEN CIRCUIT VOLTAGE V_{OC} (mV)
1	4.35	1.37	4.13	39.1	1220	1170	575
2	4.38	1.19	4.16	43.6	1280	---	---
3	4.36	1.24	4.12	41.4	1280	---	---
4	4.39	1.20	4.17	39.4	1240	1180	579
5	4.40	1.20	4.20	39.2	1240	1180	578
6	4.41	1.20	4.20	36.5	1250	1180	578
7	4.39	1.17	4.17	40.8	1300	1190	578
8	4.40	1.20	4.16	38.2	1270	1190	577
9	4.43	1.18	4.22	39.2	1260	1200	578
10	4.37	1.20	4.18	42.3	1220	1190	577
11	4.47	1.20	4.25	38.0	1230	1180	578
12	4.50	1.18	4.29	36.8	1260	1180	579
13	4.50	1.17	4.23	37.7	1230	---	---
14	4.36	1.17	4.15	36.5	1220	1180	578
15	4.33	1.18	4.19	37.2	1220	1180	576
16	4.39	1.21	4.19	35.7	1220	1190	578
17	4.32	1.20	4.12	36.1	1240	1190	577
18	4.40	1.23	4.19	35.8	1210	1190	576
19	4.34	1.24	4.14	35.0	---	---	---
20	4.43	1.18	4.20	33.0	1230	1190	578
21	4.43	1.20	4.23	---	---	---	---
22	4.28	1.18	4.09	29.6	1240	---	---
23	4.42	1.23	---	---	---	---	---
24	4.39	1.19	---	---	---	---	---
MEAN	4.39	1.20	4.18	38.1	1243	1185	578
STD. DEV.	0.05	0.04	0.05	2.6	25	7	1
% STD. DEV	1.2%	3.4%	1.1%	6.7%	2.0%	0.6%	0.2%
CUMULATIVE YIELD	N.A.	N.A.	91.7%	87.5%	83.3%	---	66.7%

TABLE 15: Wafer data for test lot no. A5

WAFER NUMBER	STARTING THICKNESS (mils)	WAFER RESISTIVITY (Ω-cm)	THICKNESS AFTER TEXTURE (mils)	JUNCTION SHEET RESISTANCE (Ω/□)	BARE SURFACE GENERATION CURRENT (mA)	COMPLETED CELL SHORT CIRCUIT CURRENT I_{SC} (mA)	COMPLETED CELL OPEN CIRCUIT VOLTAGE V_{OC} (mV)
1	7.15	1.36	7.00	34.8	1340	1270	596
2	7.29	1.35	7.05	35.7	1280	1270	594
3	7.10	1.41	6.93	37.1	1280	1270	593
4	7.18	1.41	7.02	36.4	1320	1280	593
5	7.10	1.36	6.97	37.2	1300	1290	594
6	7.16	1.39	6.98	38.3	1280	1280	594
7	7.17	1.67	7.00	39.5	1290	1280	588
8	7.14	1.68	6.99	38.4	1300	1290	588
9	7.01	1.18	6.82	39.6	1270	---	---
10	7.18	1.69	6.93	38.2	1280	1280	588
11	7.17	1.24	6.98	41.1	1260	1280	594
12	7.16	1.21	6.98	41.8	1240	1280	595
13	7.12	1.25	6.95	38.8	1250	1280	594
14	7.35	1.42	7.18	41.6	1240	1290	593
15	7.49	1.73	7.16	44.9	1260	1290	588
16	7.39	1.68	7.21	43.0	1250	1290	590
17	7.26	1.64	7.10	43.2	1260	1290	588
18	7.25	1.64	7.09	43.9	1270	1290	593
19	7.22	1.68	7.05	45.3	1260	1300	588
20	7.23	1.37	7.05	46.6	1260	1290	592
21	7.36	1.37	7.09	44.4	1280	1290	592
22	7.22	1.32	7.05	51.9	1270	1300	593
23	7.26	1.20	7.08	52.7	1260	1300	593
24	7.29	1.25	7.00	44.6	1230	1290	593
MEAN	7.22	1.44	7.03	41.5	1272	1286	592
STD. DEV.	0.11	0.19	0.09	4.7	25	9	3
% STD. DEV.	1.5%	12.9%	1.2%	11.4%	2.0%	0.7%	0.5%
CUMULATIVE YIELD	N.A.	N.A.	100%	100%	100%	---	95.8%

TABLE 16: Wafer data for test lot no. A6

WAFER NUMBER	STARTING THICKNESS (mils)	WAFER RESISTIVITY (Ω-cm)	THICKNESS AFTER TEXTURE (mils)	JUNCTION SHEET RESISTANCE (Ω/□)	BARE SURFACE GENERATION CURRENT (mA)	COMPLETED CELL SHORT CIRCUIT CURRENT I_{SC} (mA)	COMPLETED CELL OPEN CIRCUIT VOLTAGE V_{OC} (mV)
1	7.23	1.69	NOT APPLICABLE	36.9	970	1200	582
2	7.30	1.70		36.4	960	1220	585
3	7.32	1.42		36.9	970	1230	587
4	7.08	1.33		37.7	960	1230	589
5	7.11	1.33		37.4	970	1220	589
6	6.95	1.24		37.8	960	1230	591
7	7.06	1.30		39.2	960	1230	590
8	6.98	1.23		39.9	950	1230	591
9	7.06	1.37		38.7	980	1240	589
10	7.02	1.62		40.4	960	1240	587
11	7.00	1.15		37.9	950	1240	592
12	7.06	1.67		41.5	960	1240	583
13	7.13	1.69		39.3	960	1250	586
14	7.08	1.61		39.7	960	1240	580
15	7.04	1.61		38.5	980	1250	586
16	7.12	1.62		42.1	970	1240	585
17	7.09	1.61		40.1	970	*	587
18	7.02	1.67		41.2	950	*	582
19	7.11	1.69		35.8	930	---	---
20	7.08	1.70		41.5	970	*	586
21	7.06	1.31		43.8	940	---	---
22	7.07	1.32		44.6	940	*	587
23	7.14	1.61		47.2	950	1250	578
24	7.09	1.65		45.6	960	1240	577
MEAN STD. DEV. % STD. DEV.	7.09 0.09 1.2%	1.51 0.19 12.4%		39.8 2.8 7.0%	960 12 1.3%	1234 12 1.0%	586 4 0.7%
CUMULATIVE YIELD	N.A.	N.A.	N.A.	100%	100%	---	91.7%

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KEUFFEL & ESSER CO.

A1 #8
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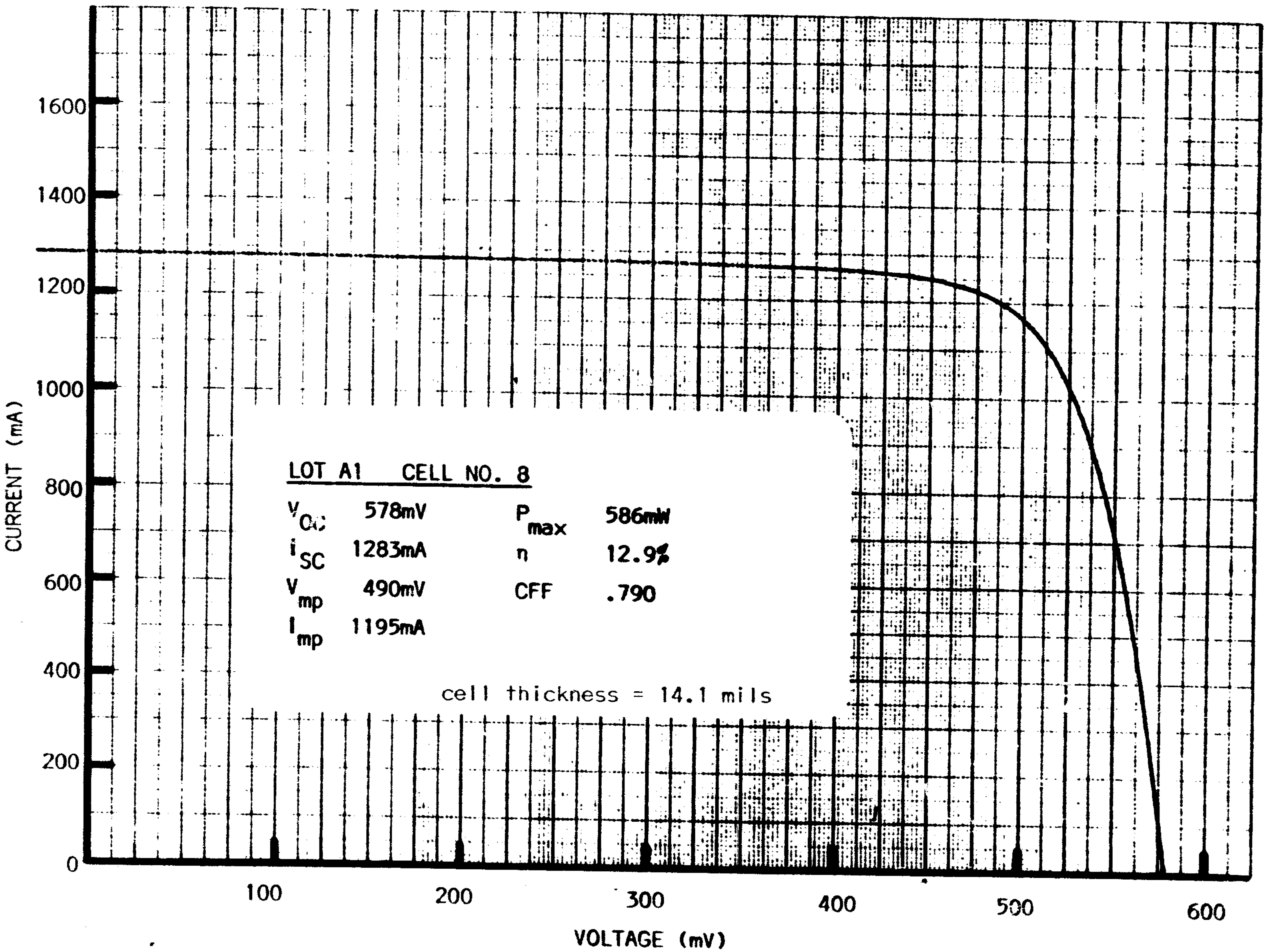


FIGURE 2: Representative AM1 current-voltage response curve for test lot no. A1

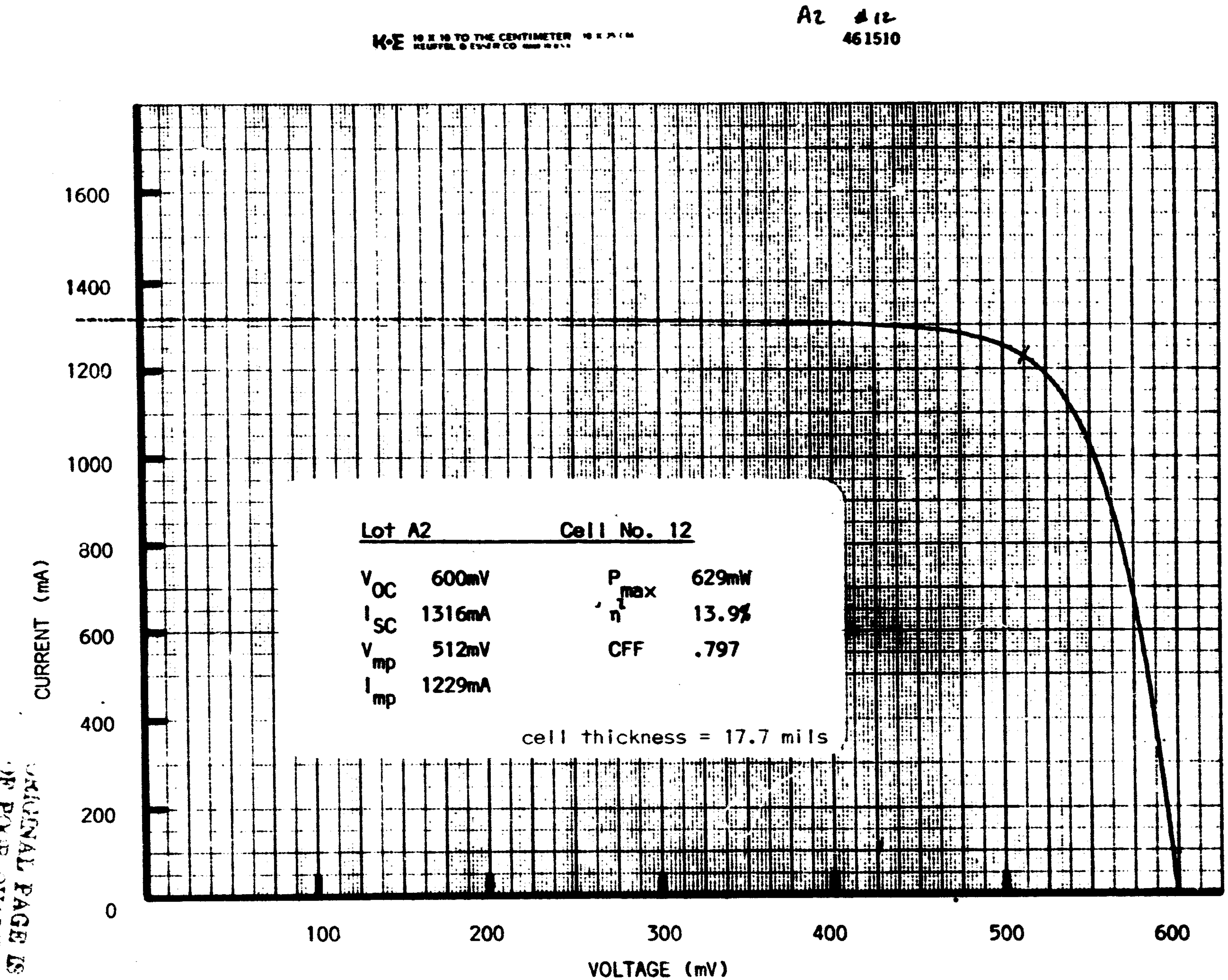


FIGURE 3: Representative AM1 current-voltage response curve for test lot no A2

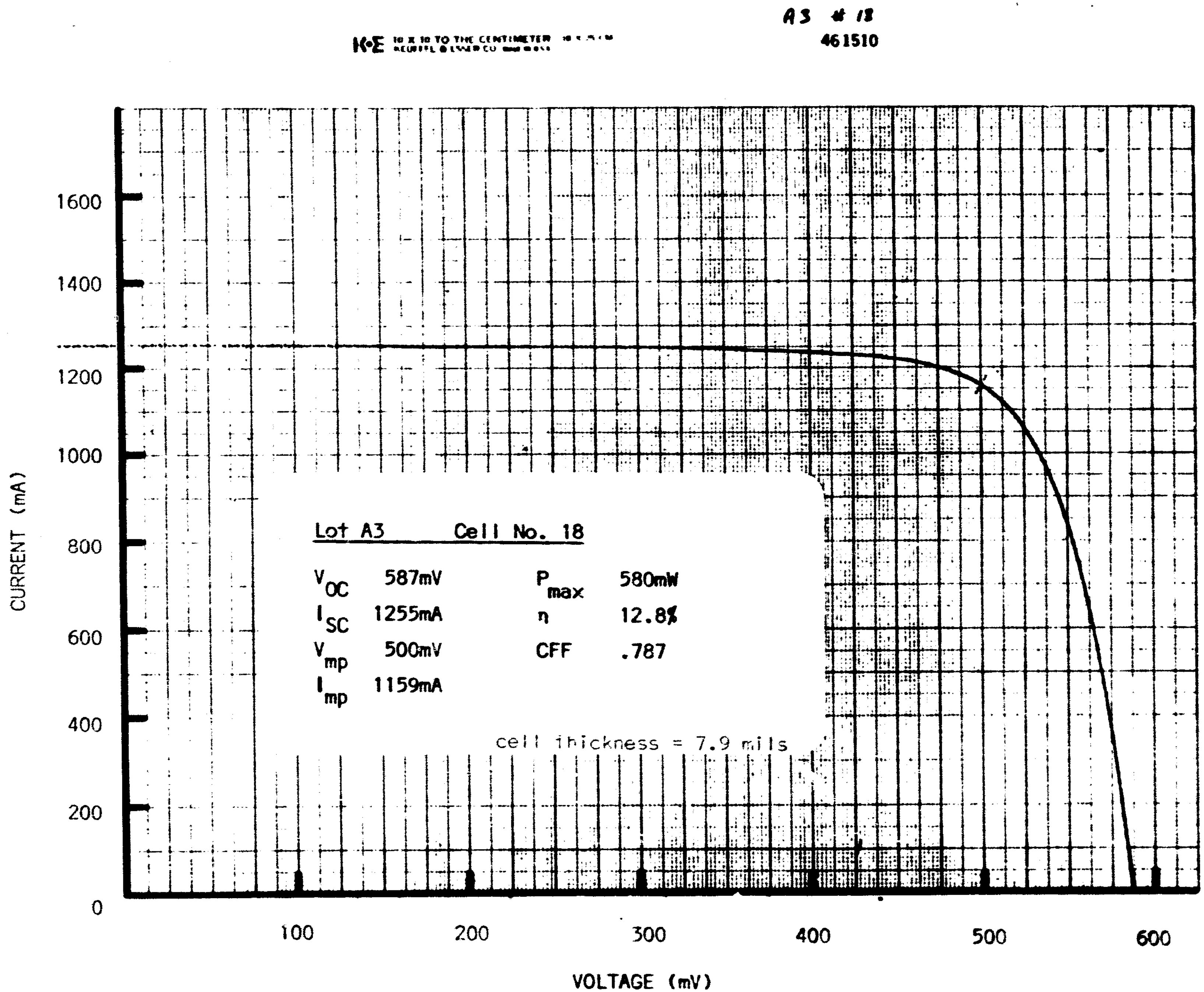


FIGURE 4: Representative AM1 current-voltage response curve for test lot no. A3.

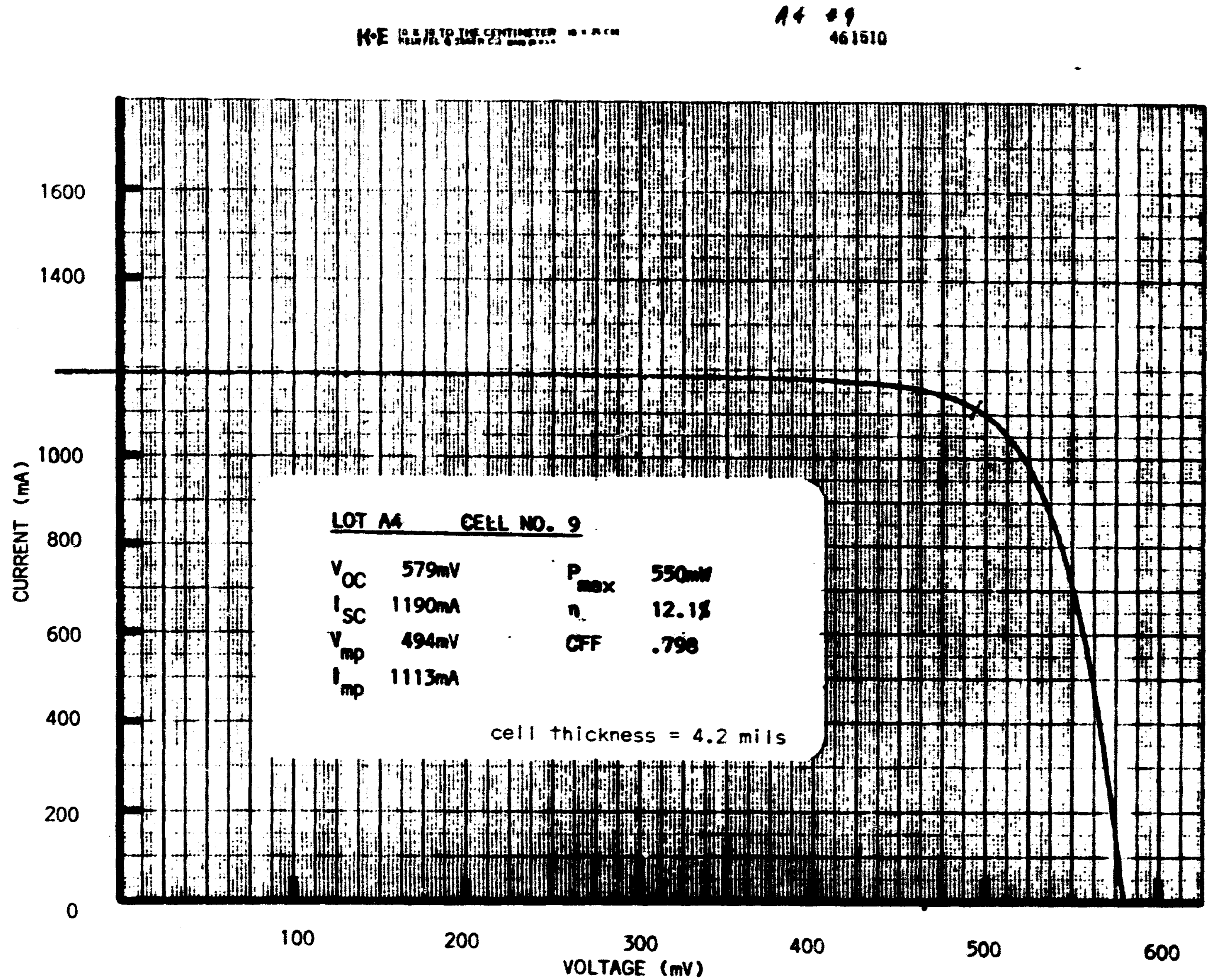


FIGURE 5: Representative AM1 current-voltage response curve for test lot no. A4.

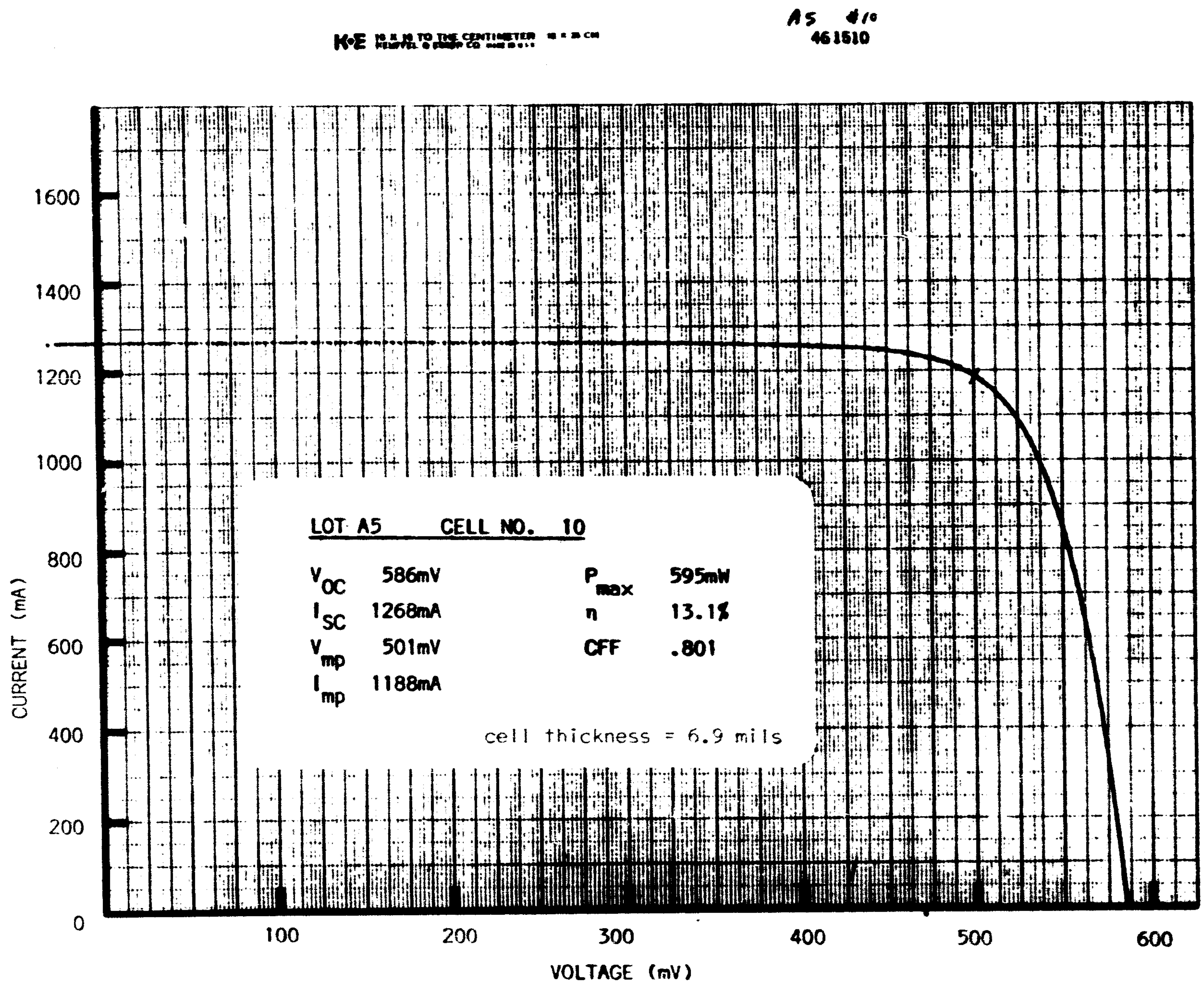


FIGURE 6: Representative AM1 current-voltage response curve for test lot no. A5.

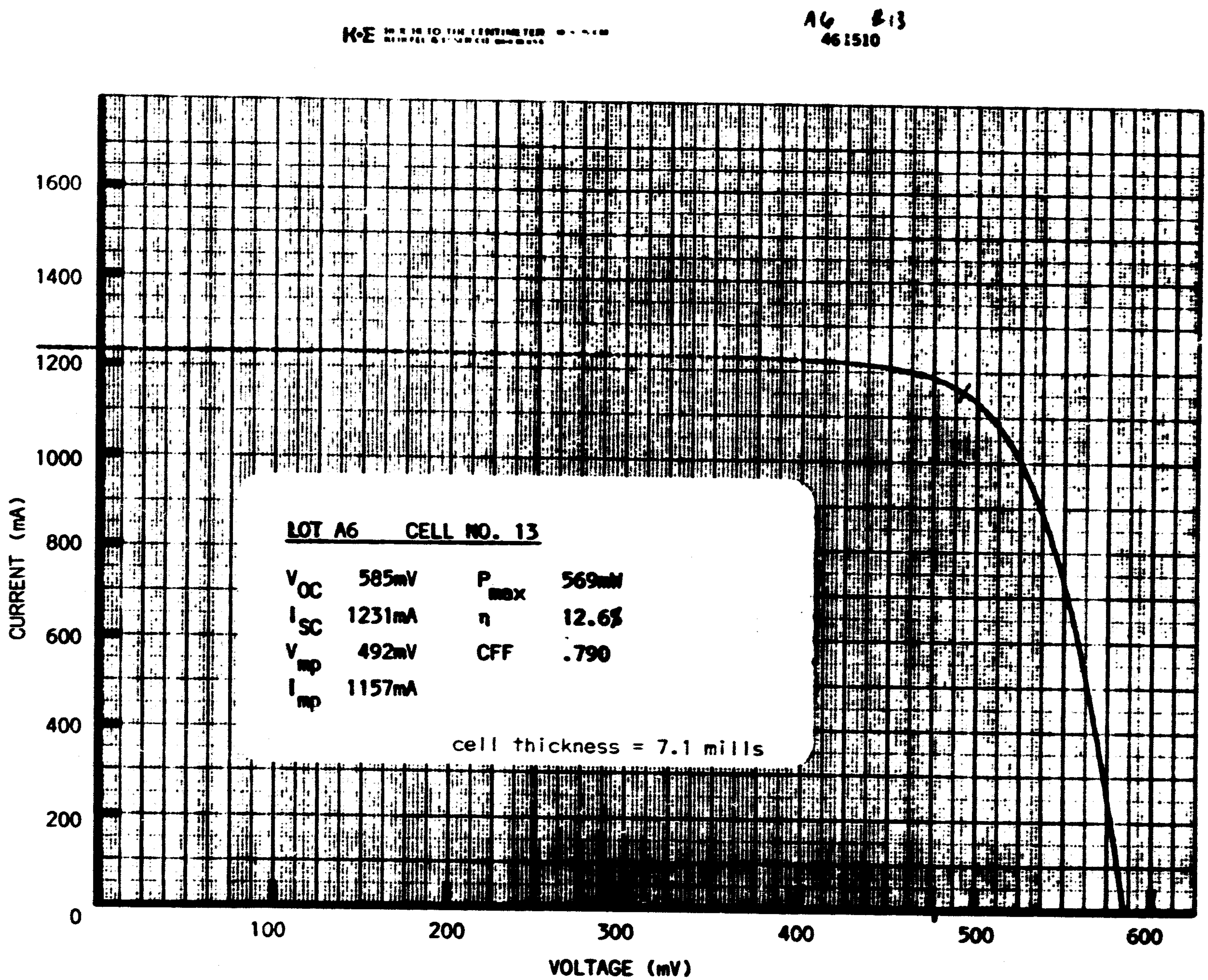


FIGURE 7: Representative AM1 current-voltage response curve for test lot no. A6.

standard deviation is the standard deviation divided by the mean and multiplied by 100.

Each of the current-voltage curves given in Figures 2 through 7 represents a sample from lots A1 through A6, respectively. Data taken and computed from the curves include V_{OC}, I_{SC}, maximum power voltage (V_{mp}), maximum power current (I_{mp}), P_{max}, power conversion efficiency (η), and curve fill factor (CFF). Efficiency numbers are based on the total area of a three inch diameter silicon wafer with flats (45.35 cm^2), for which the junction mesa pattern and the metallization grid pattern are designed. If only the p-n junction area (including metal shadowing) were considered, or if the junction were formed to the edge of the wafer, the efficiency values given would be increased by an additional 0.6% (i.e., η = 13.9% would become η = 14.5%). The cell data for each of the samples of Figures 2 through 7 are summarized in Table 17.

Diffusion length and spectral response measurements were performed on each of the samples listed in Table 17. Diffusion length measurements were made on the completed cells by the open circuit photovoltage (OCPV) method, a variation of the surface photovoltage (SPV) technique. With this method, the open circuit voltage generated by incident monochromatic light at various wavelengths is monitored and held constant by varying input light intensity. From these data a graphical calculation is made for effective minority carrier diffusion length. With most techniques in general, it is difficult to obtain an absolute value for the diffusion length, but the relative results with the OCPV technique should be meaningful because this technique mimics actual solar cell operation.

The specific diffusion length measurements are given in Table 18. The numbers presented there are reasonable and are consistent with the cell electrical performance summarized in Table 17. The wafers of lots A3, A4, A5, and A6 were prepared from similar material and have similar diffusion lengths. The lower value for cell

TABLE 17: SOLAR CELL CHARACTERISTICS FOR SPECIFIC SAMPLES FROM LOTS A1 THROUGH A6.

LOT NUMBER	CELL NUMBER	CELL THICKNESS (mils)	V_{OC} (mV)	I_{SC} (mA)	V_{MP} (mV)	I_{MP} (mA)	P_{max} (mW)	η (%)	CFF
A1	8	14.10	578	1283	490	1195	586	12.9	.790
A2	12	17.70	600	1316	512	1229	629	13.9	.797
A3	18	7.85	587	1255	500	1159	580	12.8	.787
A4	9	4.22	579	1190	494	1113	550	12.1	.798
A5	10	6.93	586	1268	501	1188	595	13.1	.801
A6 *	13	7.13	585	1231	492	1157	569	12.6	.790

* NOTE: **Cell A6-13 was not textured, all others were.**

Lots A1 through A6 were prepared with no back surface field or enhancement.

TABLE 18: DIFFUSION LENGTH MEASUREMENTS FOR BASELINE SOLAR CELL SAMPLES.

LOT NUMBER	CELL NUMBER	CELL THICKNESS (mils)	OCPV DIFFUSION LENGTH (microns)
A1	8	14.10	68
A2	12	17.70	93
A3	18	7.85	23
A4	9	4.22	37
A5	10	6.93	39
A6	13	7.13	38

A3-18 is probably explained by the fact that A3-18 was prepared from an as-sawed wafer, without saw damage removal before texturing. The wafers in A4, A5, and A6 were chem-etched after sawing. In general, the diffusion lengths for lots A3-A6 are lower than may be desired, but this is likely a result of the material preparation and growth process. Lots A1 and A2 are each from material independently prepared. The 93 μm diffusion length for A2-12 is respectable, and this is reflected in the good infrared response discernable in a spectral response measurement for this cell.

The relative spectral response for each of the sample cells discussed above was measured using a Cary 17 Spectrophotometer. The relative response curves are shown in Figures 8 through 13 for cells from lots A1 through A6, respectively. The spectral response measurments agree with the diffusion length data provided in Table 18. Cells A5-10 and A6-13 are about the same thickness and have the same diffusion length and their spectral response curves are virtually identical. Cell A3-18, which has a lower diffusion length, shows a decreased infrared response compared to A5-10 and A6-13. The irregular bump in the response curve for A3-18 near 0.53 micron is believed to be an artifact of the particular measurement and not an actual response. In the region 0.40 to 0.55 micron, this curve should probably be shifted downward slightly to blend more smoothly with the rest of the curve beyond 0.55 micron. As noted earlier, the relative response for cell A2-12, which has a measured diffusion length of 93 microns, shows very good performance in the long wavelength region.

3.5.4 RELATIVE PERFORMANCE VERSUS THICKNESS

With inclusion of the spectral response and diffusion length data, analysis of the results of the baseline process sequence is essentially complete. In general, the simple phosphorus diffused cells from lots A1 through A6 performed just as expected. The important correlation is that, without a back surface enhancement

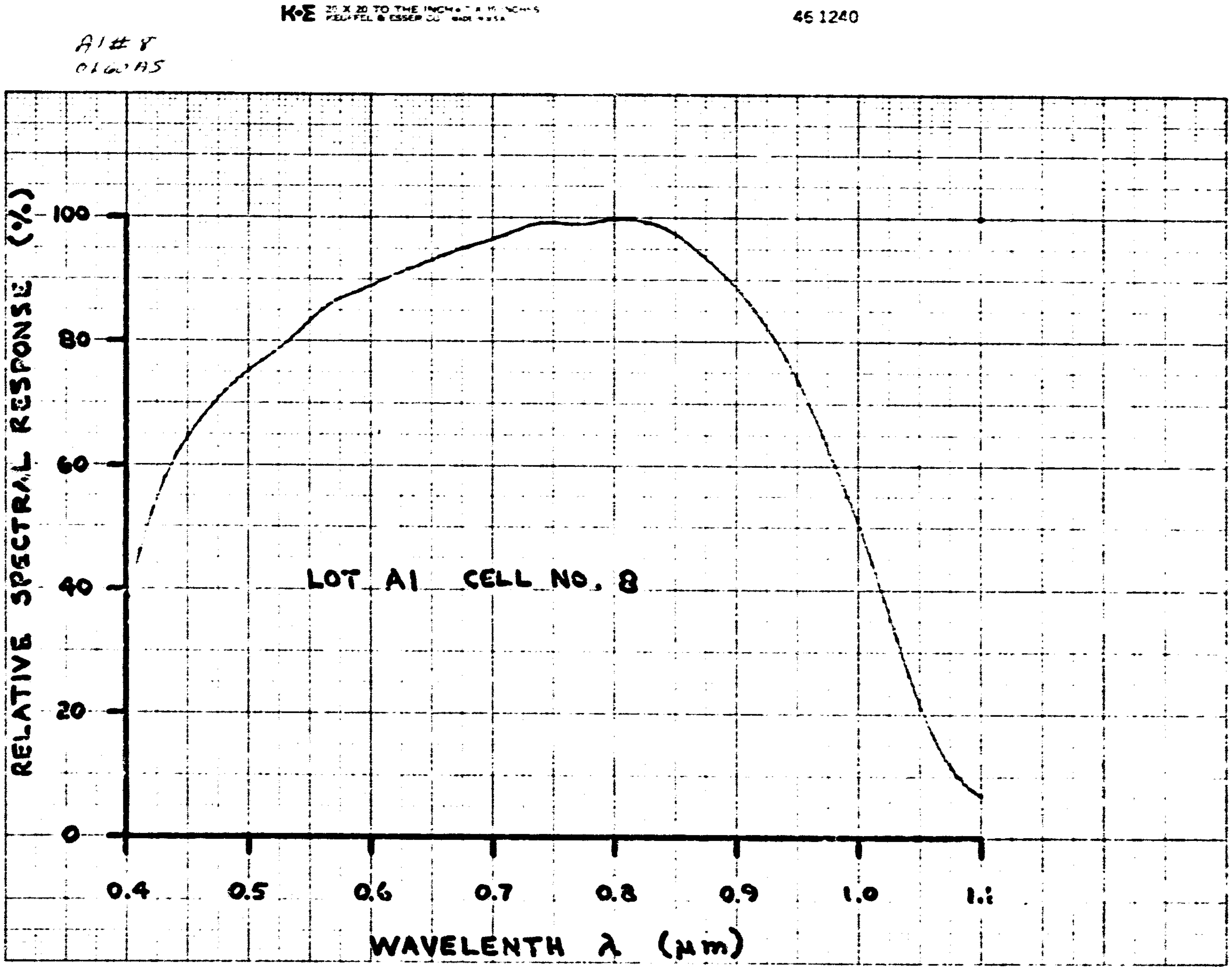


FIGURE 8: SPECTRAL RESPONSE OF TEXTURED CELL ON 14.10 MIL, 2.30 Ω-cm SUBSTRATE.

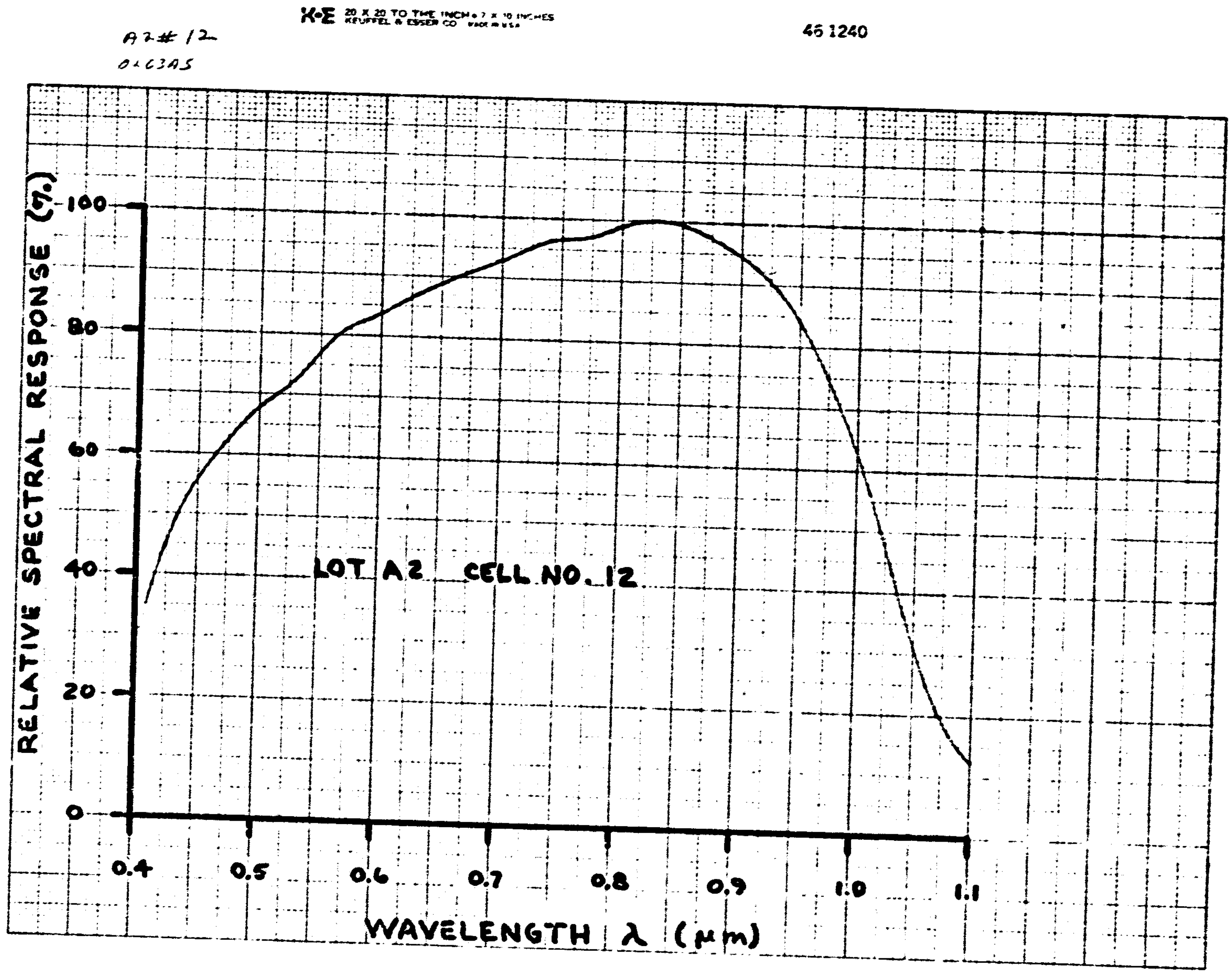


FIGURE 9: SPECTRAL RESPONSE OF TEXTURED CELL ON 17.70 MIL, 1.12 Ω-cm SUBSTRATE.

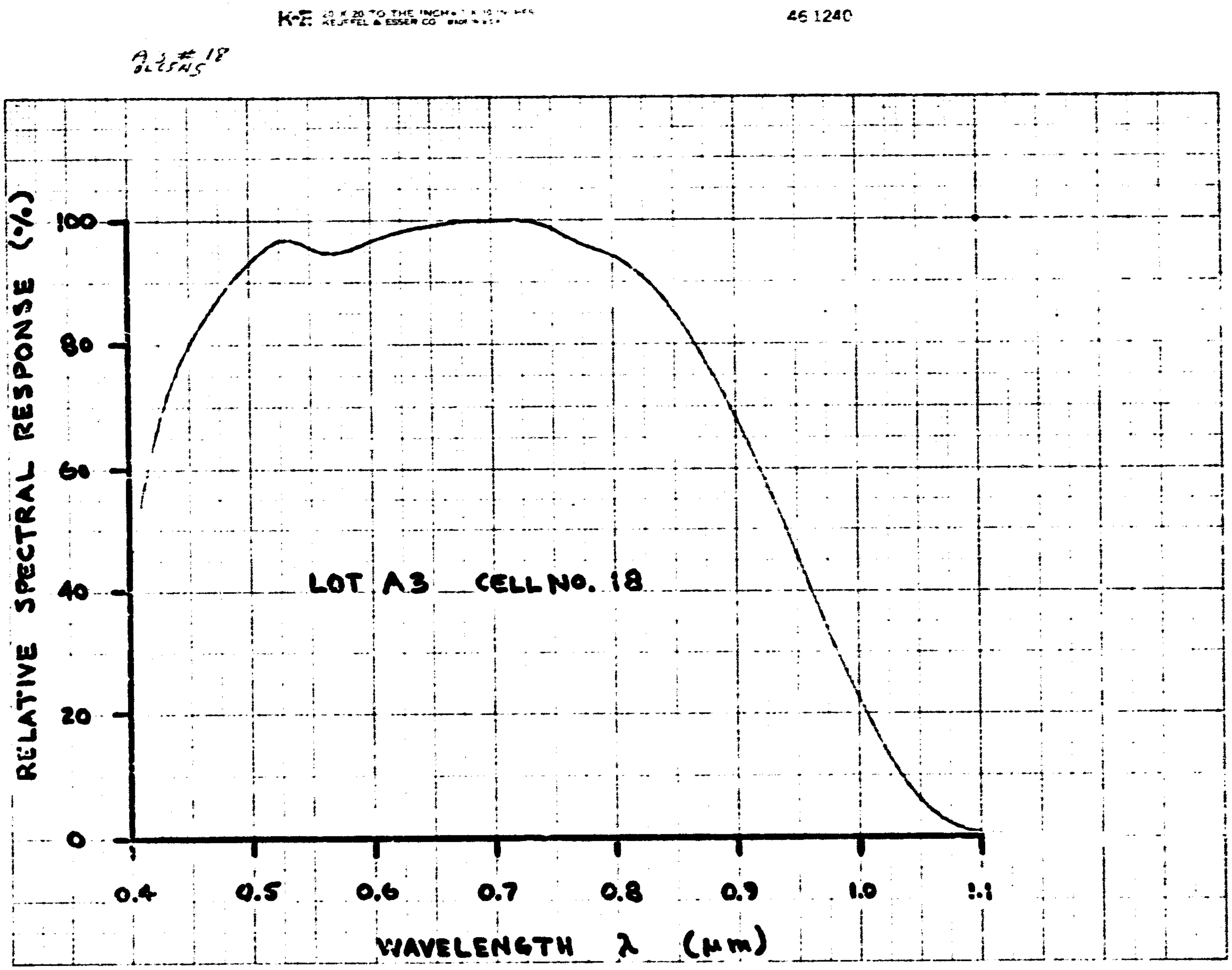


FIGURE 10: SPECTRAL RESPONSE OF TEXTURED CELL ON 7.85 MIL, 1.33 Ω-cm SUBSTRATE.

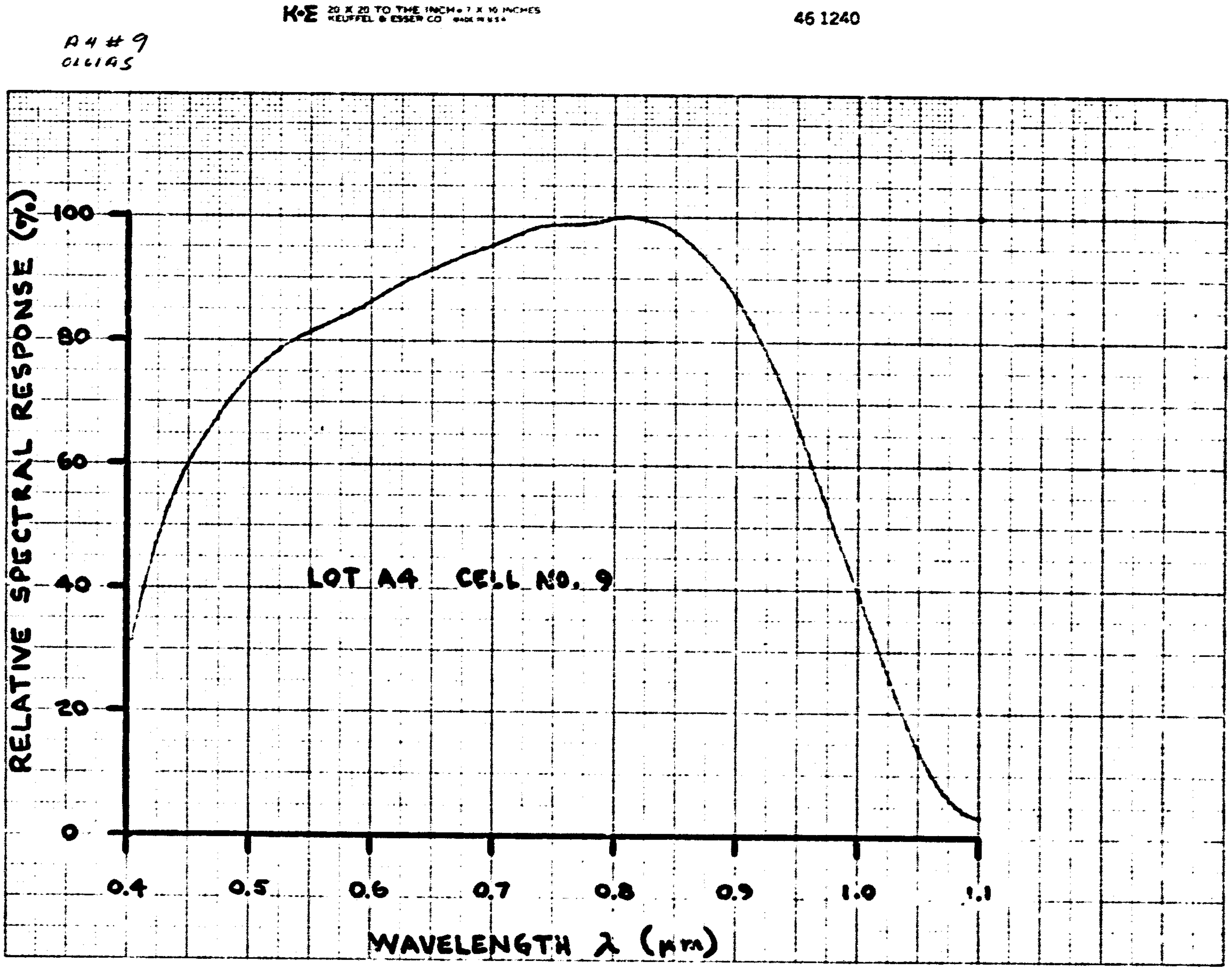


FIGURE 11: SPECTRAL RESPONSE OF TEXTURED CELL ON 4.22 MIL, 1.18 Ω-cm SUBSTRATE.

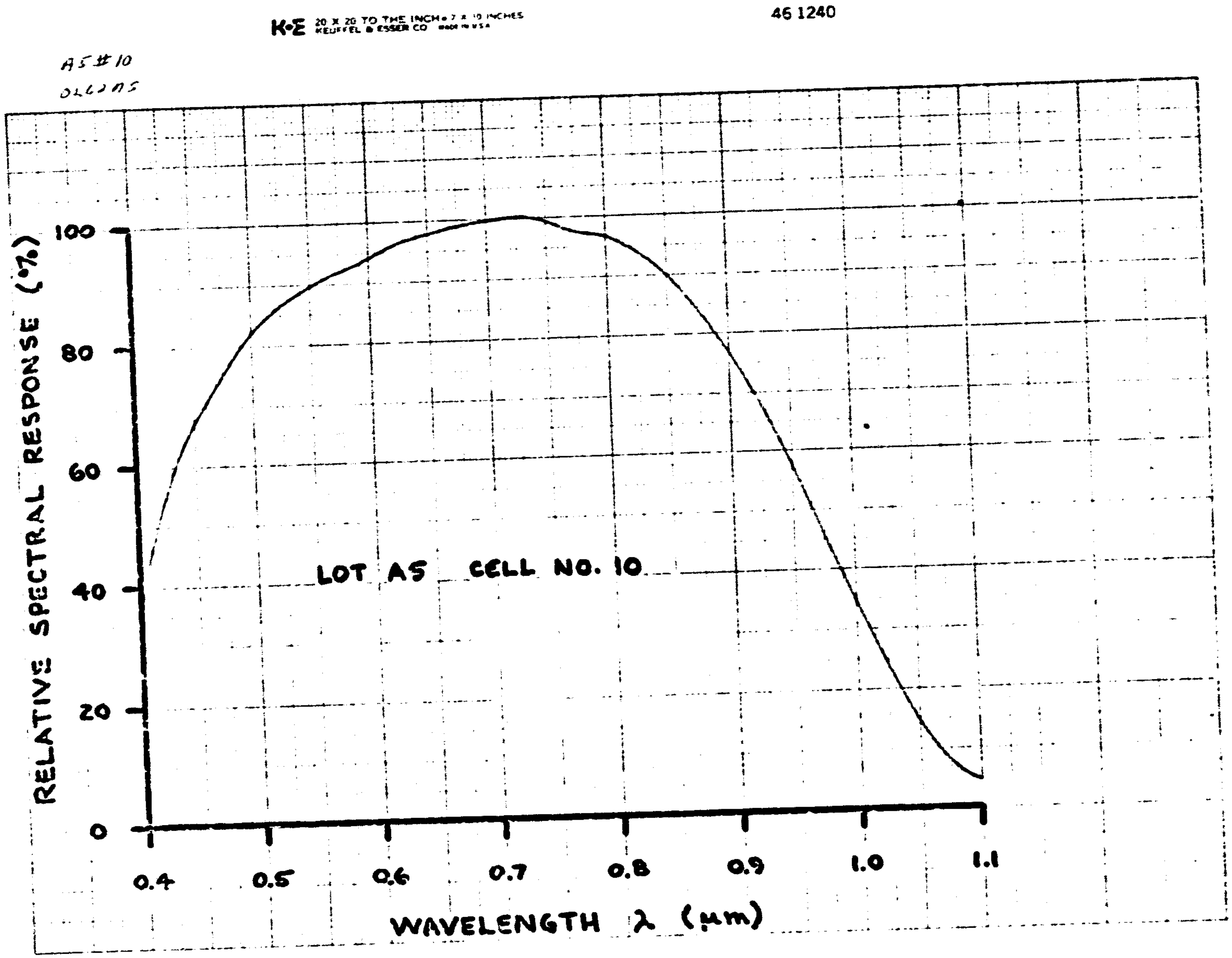


FIGURE 12: SPECTRAL RESPONSE OF TEXTURED CELL ON 6.93 MIL, 1.69 Ω-cm SUBSTRATE.

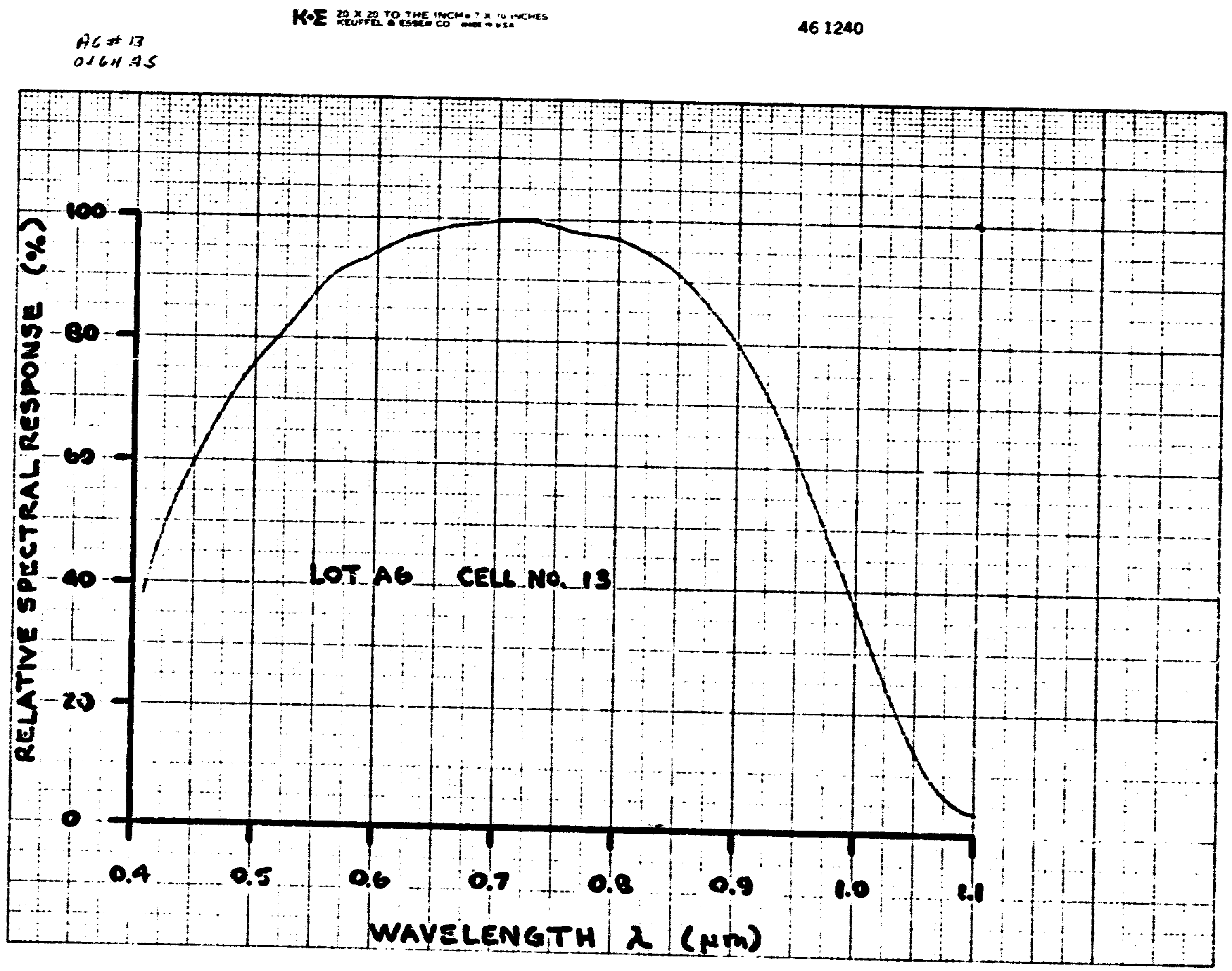


FIGURE 13: SPECTRAL RESPONSE OF NON-TEXTURED CELL ON 7.13 MIL, 1.69 Ω-cm SUBSTRATE.

diffusion or back surface field (BSF), the cell efficiency decreases as the substrate is made thinner. Combining the results of the data from lots A2, A4, and A5 (which have similar substrate resistivities and are textured), the relative performance versus thickness is summarized in Table 19. It should be noted that there is a small loss (3.2%) of available power using 7.0 mil substrates and a significant loss (12.9%) using 4.2 mil substrates. Again it must be emphasized that no back surface enhancement was used and that the use of a BSF layer should be capable of increasing the performance of both the 7.0 mil and 4.2 mil substrates.

3.6 PROCESS ADAPTATIONS

3.6.1 CELL STRUCTURE IMPROVEMENTS WITH DIFFUSION PROCESS

Previous experimental studies (lots A1 - A6) determined the effects of substrate thinness on solar cell performance for a baseline process sequence which resulted in a simple n+p solar cell structure. This process sequence formed the n+ layer with a phosphine diffusion step. It was anticipated that the inclusion of a back surface enhancement diffusion of p-type dopant to form a back surface field (BSF) region would significantly enhance the performance of the thinnest substrates.

To study this possibility a test matrix of six lots (D1 through D6) was established. Lots D1, D2, and D3 consist of 24 wafers each of nominally 7 mil substrates (sawed to 8 mils and chem-etched to 7 mils) while lots D4, D5, and D6 consist of 24 wafers each of nominally 4 mil substrates (sawed to 5 mils and chem-etched to 4 mils). A planar process was used to define a phosphorus diffused junction for all six lots. In addition, lots D1 and D4 received a back surface boron diffusion at 1000°C to form a p+ layer. Lots D2, D3, D5, and D6 served as controls. The test matrix is outlined in Table 20.

TABLE 19: RELATIVE PERFORMANCE FOR SUBSTRATES OF DIFFERENT THICKNESS.

SUBSTRATE THICKNESS	MEASURED CELL PARAMETERS V_{OC} (mV)	I_{SC} (mA)	RELATIVE OUTPUT POWER
17.4 mils	602	1306	100%
7.0 mils	592	1286	96.8%
4.2 mils	578	1185	87.1%

Data are based on lot averages for lots A2, A4, and A5 which consist of textured cells with phosphorus diffused n-on-p structure, mesa etched edges, and no back surface enhancement.

TABLE 20: BACK SURFACE ENHANCEMENT TEST MATRIX

STEP	LOT NUMBERS		
	D1, D4	D2, D5	D3, D6
1. Si_3N_4 deposition for mask	yes	yes	yes
2. Strip wafer back	yes	no	no
3. BCl_3 deposition and oxidation	yes	yes	no
4. Planar pattern front	yes	yes	yes
5. Texture etch	yes	yes	yes
6. PH_3 diffusion	yes	yes	yes
7. Strip wafer dielectrics	yes	yes	yes
8. Si_3N_4 AR coat	yes	yes	yes
9. Metal pattern etch	yes	yes	yes
10. Metal plate	yes	yes	yes
Final cell structure	n+pp+	n+p	n+p

Wafer Thickness:

D1, D2, D3 7 mils

D4, D5, D6 4 mils

Table 20 lists the process steps used and the order of their occurrence. Where a "no" is entered into the table the particular step was omitted. Lots D1 and D4 have an n+pp+ structure while the other lots have only the baseline n+p structure for direct comparison. The process sequence for lots D3 and D6 simply omits the boron trichloride (BCl_3) diffusion step. The sequence for lots D2 and D5 incorporates the boron diffusion cycle but masks the substrate from the effects of boron diffusion with a protective layer of silicon nitride (Si_3N_4). This was done to provide a control group of cells with the simple n+p structure but one which has undergone the additional thermal cycle of the 1000°C BCl_3 deposition which the test lots D1 and D4 must experience.

The thickness and resistivity of each wafer started in lots D1 through D6 was measured before processing. The average thickness for substrates in lots D1, D2, and D3 was 7.19 mils (0.12 mil standard deviation) and the average resistivity was 1.70 Ω-cm (0.27 Ω-cm standard deviation). The average thickness for substrates in lots D4, D5, and D6 was 4.29 mils (0.06 mil standard deviation) and the average resistivity was 1.28 Ω-cm (0.11 Ω-cm standard deviation).

A comparison of typical I-V characteristic curves for cells from lots D1 and D2 is shown in Figure 14 and a comparison for D4 and D5 is shown in Figure 15. In general, the p+ back surface enhancement effected a significant improvement for the 7.2 mil substrates, while, for the 4.3 mil substrates, the improvement was marginal. It is likely that this difference in effectiveness is due to the non-optimum back surface field (BSF) created with the particular boron enhancement layer. With the very thin substrates, BSF conditions probably need to be much closer to ideal to mask the front surface junction from the effects of back surface recombination.

It should be noted that, as for the case of test lots A1 through A6, a totally plated metallization system was employed for lots D1 through D6. However,

FIGURE 14: COMPARISON OF CHARACTERISTIC CURVES FOR LOTS D1 AND D2.

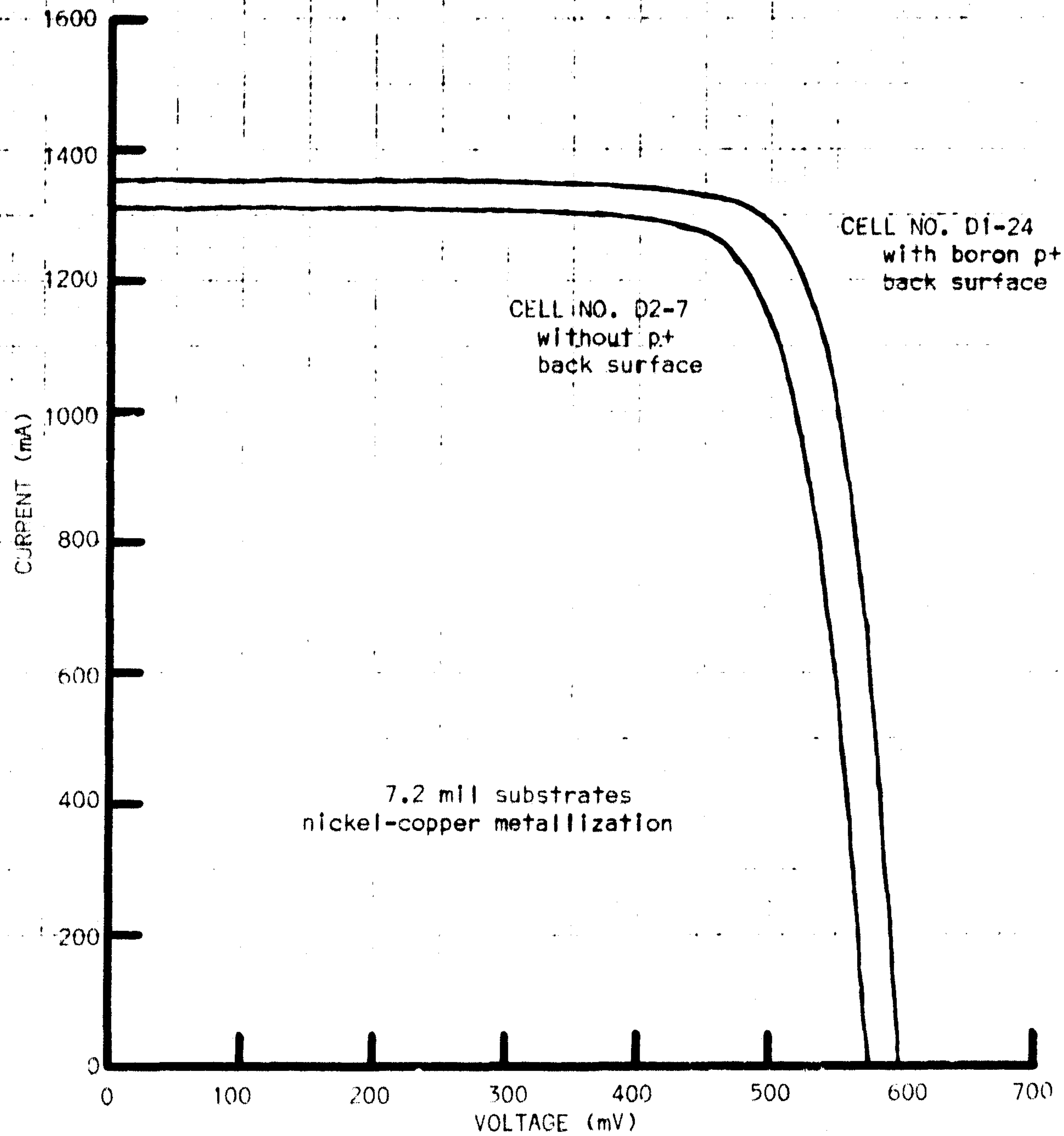
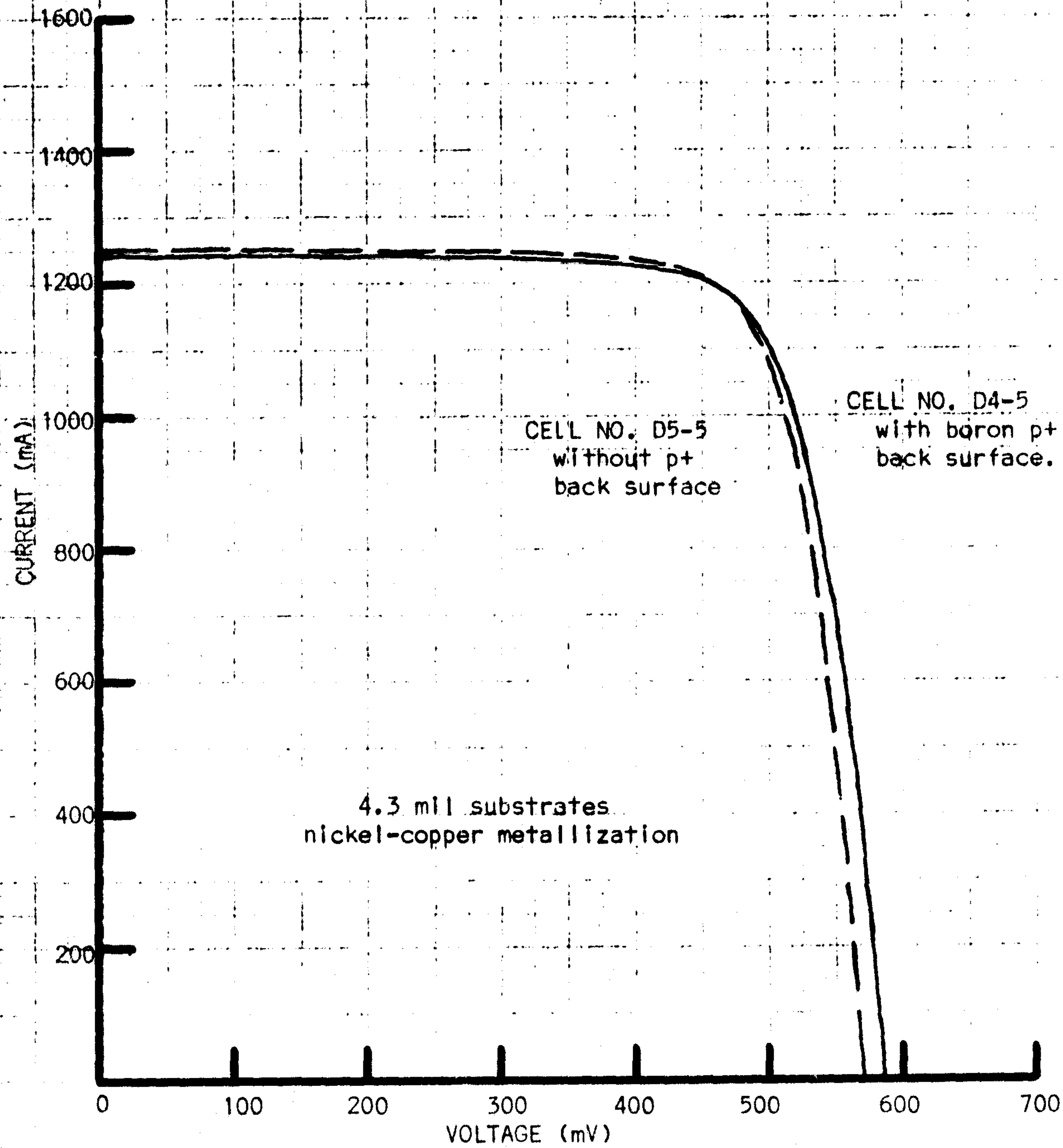


FIGURE 15: COMPARISON OF CHARACTERISTIC CURVES FOR LOTS D4 AND D5.



this time a nickel-copper system was used, with copper serving as the conductive layer rather than silver.

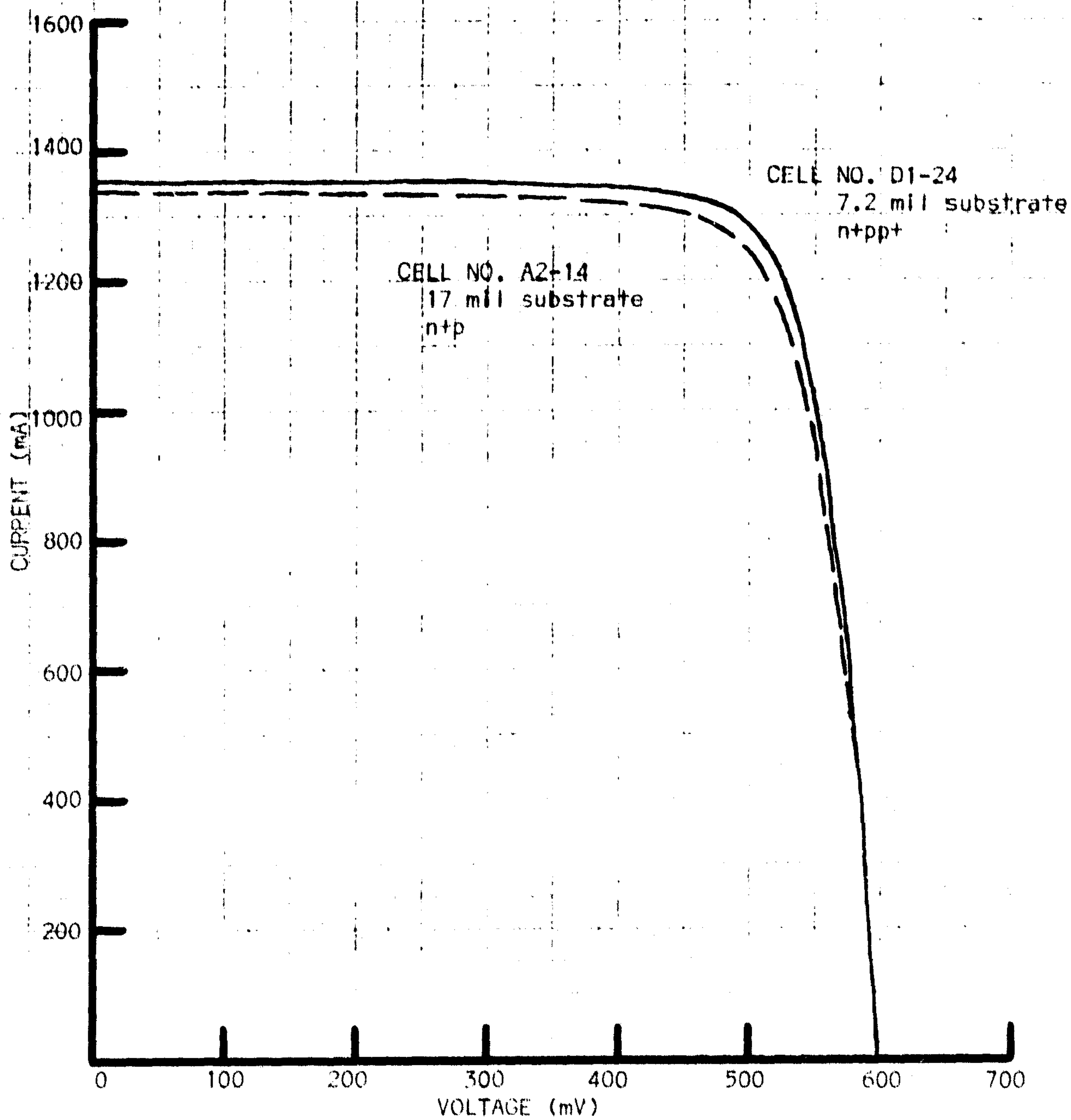
It is interesting to compare the 7.2 mil, diffused n+pp+ device performance with the 17 mil n+p devices discussed in Section 3.5. Figure 16 shows such a comparison. With the incorporation of a p+ (boron) back surface enhancement layer, the solar cells on 7 mil substrates are capable of equalling the performance of solar cells on 17 mil substrates.

3.6.2 INITIAL ION IMPLANTATION INVESTIGATIONS

A major processing adaptation which may improve yield and throughput of the cell fabrication process is the use of ion implantation in place of diffusion. With implantation techniques, a back surface p-type enhancement can easily be incorporated to fabricate an n+p-p+ type cell. This should result in improved performance from the thin substrates. By using ion implantation for both the front surface phosphorus junction layer formation and the back surface boron enhancement layer formation, handling of the substrates is minimized and processing sequences are greatly simplified over those for all-diffusion processes. This simplification of processing and minimization of handling will enhance the ability to maintain high processing yields regardless of substrate thickness.

First experiments using ion implantation with thin substrates were attempts to reproduce the baseline process cell structure so that results would be comparable to the data of lots A1 through A6, discussed earlier. Wafers sawed to 8 mils and chem etched to 7 mils for saw damage removal were assembled in lot B8. The average measured wafer thickness for this lot was 7.22 mils. Wafers sawed to 5 mils and etched to 4 mils comprised lot B7. The average measured thickness for B7 was 4.36 mils. None of these wafers were textured.

FIGURE 16: COMPARISON OF CHARACTERISTIC CURVES FOR LOTS D1 AND A1.



Some of the wafers in B7 and B8 were ion implanted with phosphorus to form a front junction. After annealing, these cells underwent a mesa etch process to provide a junction area identical to the areas of lots A1 through A6. A silicon nitride AR coating was deposited, and this coating was patterned to form the front ohmic contact grid. The exposed silicon in this pattern was plated with the palladium-silver metallization system.

A number of the completed cells displayed somewhat undesirable series resistance and shunt problems. The exact reason for this has not been determined but it may be related to difficulties with the mesa etch process. Two of the better cells are characterized in Figures 17 and 18. Figure 17 shows cell No. 6 from lot B7. This cell is 4.4 mils thick and is not textured. The short circuit current value of 1205 mA is slightly better than the average for the diffused process lot A4, which was 1185 mA. However, open circuit voltage is lower for B7-6, being 560 mV compared to 578 mV for lot A4. Note, however, that lot A4 was textured.

Figure 18 shows cell No. 3 from lot B8. This cell is 7.2 mils thick and is not textured. As such, it should be directly comparable to the data of lot A6, which consisted of the same non-textured material. The I_{SC}, V_{OC} values of 1190 mA, 567 mV for B8-3 are slightly lower than the average values 1234 mA, 586 mV for lot A6.

The first attempts at an ion implant process sequence were encouraging. Several refinements in the implantation process sequence were then pursued. Candidate ion implantation processes considered included phosphorus implanted front junctions and boron implanted back surface enhancements. Process variations studied included implanting to the wafer edge with both phosphorus front and boron back implants and masking either the front or back implants to prevent formation of a possible "high-leakage" p+n+ junction at the wafer edge. These experiments are tabulated in the next section.

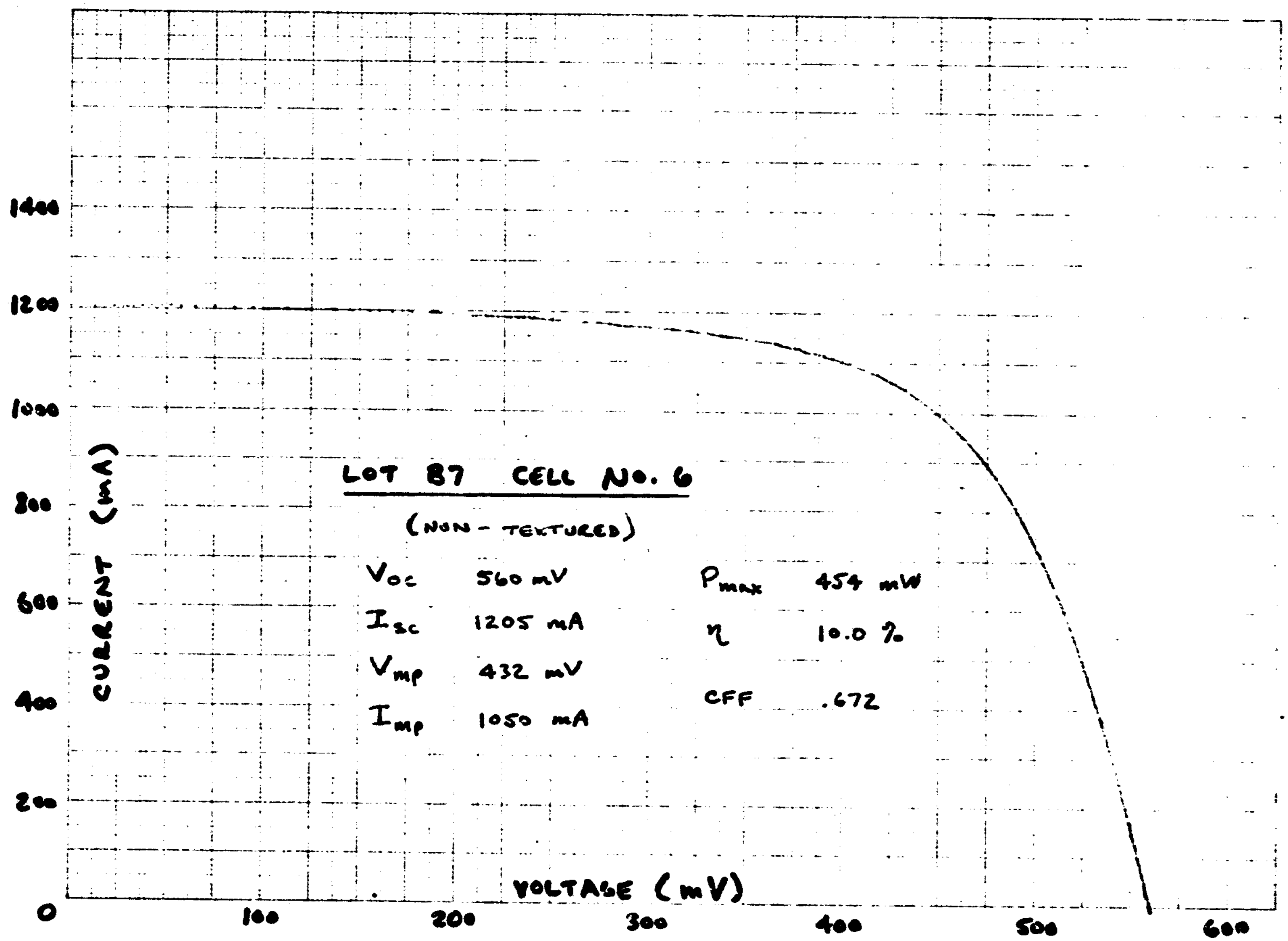


FIGURE 17: ONE SUN I-V CHARACTERISTIC FOR FIRST ATTEMPT, NON-OPTIMIZED ION IMPLANT PROCESS SEQUENCE WITH 4.4 MIL SUBSTRATE.

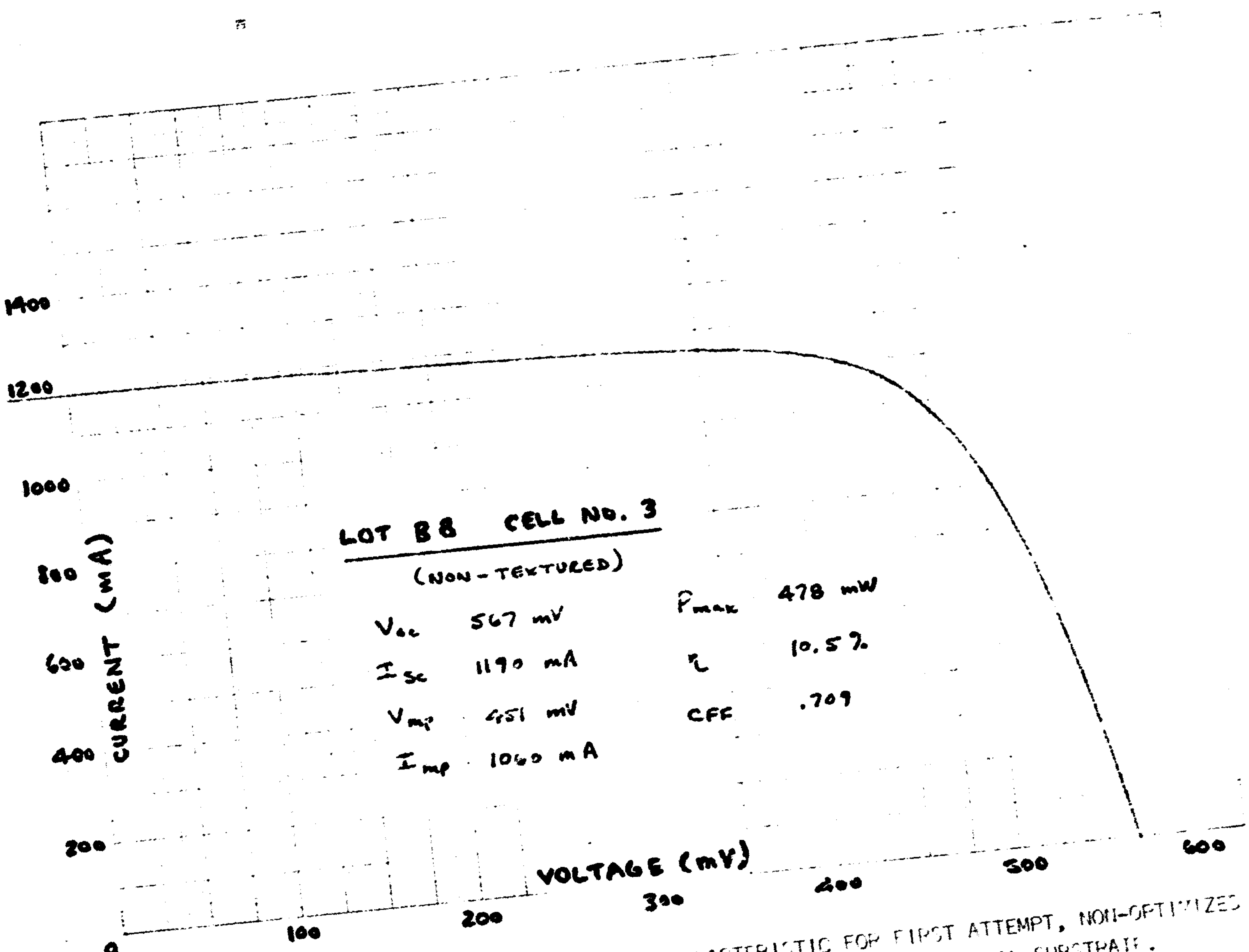


FIGURE 18: ONE SUN I-V CHARACTERISTIC FOR FIRST ATTEMPT, NON-OPTIMIZED ION IMPLANT PROCESS SEQUENCE WITH 7. MIL SUBSTRATE.

3.6.3 EXPERIMENTAL MATRIX SUMMARY

A summary of experimental lots studied is given in Table 21. This summary notes the type of wafer and cell structure, as well as whether ion implantation or diffusion was used for processing. A few of the lots were abandoned before being completed. Lots B1, B5, and C2 were abandoned at metallization. Lot C2 could not be plated because of incomplete etching of the metal pattern into the silicon nitride coating. Lots B1 and B5 exhibited large shunts because of metal plating on the wafer edges.

Most of the lots designated as using an ion implantation process were attempts to optimize processing sequences for the 7 mil and 4 mil thick substrates. The culmination of this effort is represented by lot D30. Lot D30 was split in half. One half of the lots was given a back-surface boron implant to form an enhancement layer, the other half was not. Figure 19 shows current-voltage characteristic curves for two cells from D30 -- one with a boron back implant and one without. The important observation is that with the boron implant, the 7 mil thick cell performs as well as a 17 mil, phosphorus diffused cell from lot A2. This is exemplified in Figure 20. The process sequence for D30 is given in Table 22.

3.6.4 PILOT PROCESS CHOICE

On the strength of the good performance obtained from lot D30, an ion implantation process was chosen for the pilot process sequence. Using ion implantation techniques will ultimately allow minimization of the number of times individual substrates must be handled. The basic outline for the pilot line process is listed in Table 23. This outline is detailed, and the pilot process experiments are discussed, in Section 3.7.

TABLE 21: SUMMARY OF EXPERIMENTAL LOTS INITIATED FOR THIN CELL PROCESSING DEVELOPMENT.

KEY: WAFER TYPE

I	as-cut to 8 mils, 1.5 Ω-cm
II	cut to 8 mils, chem-etched to 7 mils, 1.5 Ω-cm
III	cut to 5 mils, chem-etched to 4 mils, 1.5 Ω-cm
IV	as-cut to 17 mils, 1.0 Ω-cm
V	chem-etched and polished to 14 mils, 2.3 Ω-cm

CELL TYPE

D	diffused
I	ion implanted
M	mesa etched
P	planar
E	implanted to edge
STD	n+p
BSF	n+pp+

LOT NO.	WAFER TYPE	TEXTURED SURFACE	CELL TYPE
A1	V	yes	D, M, STD
A2	IV	yes	D, M, STD
A3	I	yes	D, M, STD
A4	III	yes	D, M, STD
A5	II	yes	D, M, STD
A6	II	no	D, M, STD
B1	II	yes	I, E BSF
B2	II	no	I, P, BSF
B3	II	yes	I, P, BSF
B4	III	yes	---
B5	III	yes	I, E, BSF
B6	III	no	I, P, BSF
B7	III	no	I, M, STD & BSF
B8	II	no	I, M, STD & BSF
C1	II	yes	I, E, BSF
C2	II	yes	I, E, BSF
D1	II	front	D, P, BSF
D2	II	front	D, P, STD
D3	II	front	D, P, STD
D4	III	front	D P, BSF
D5	III	front	D, P, STD
D6	III	front	D, P, STD
D30	II	yes	I, P, STD & BSF

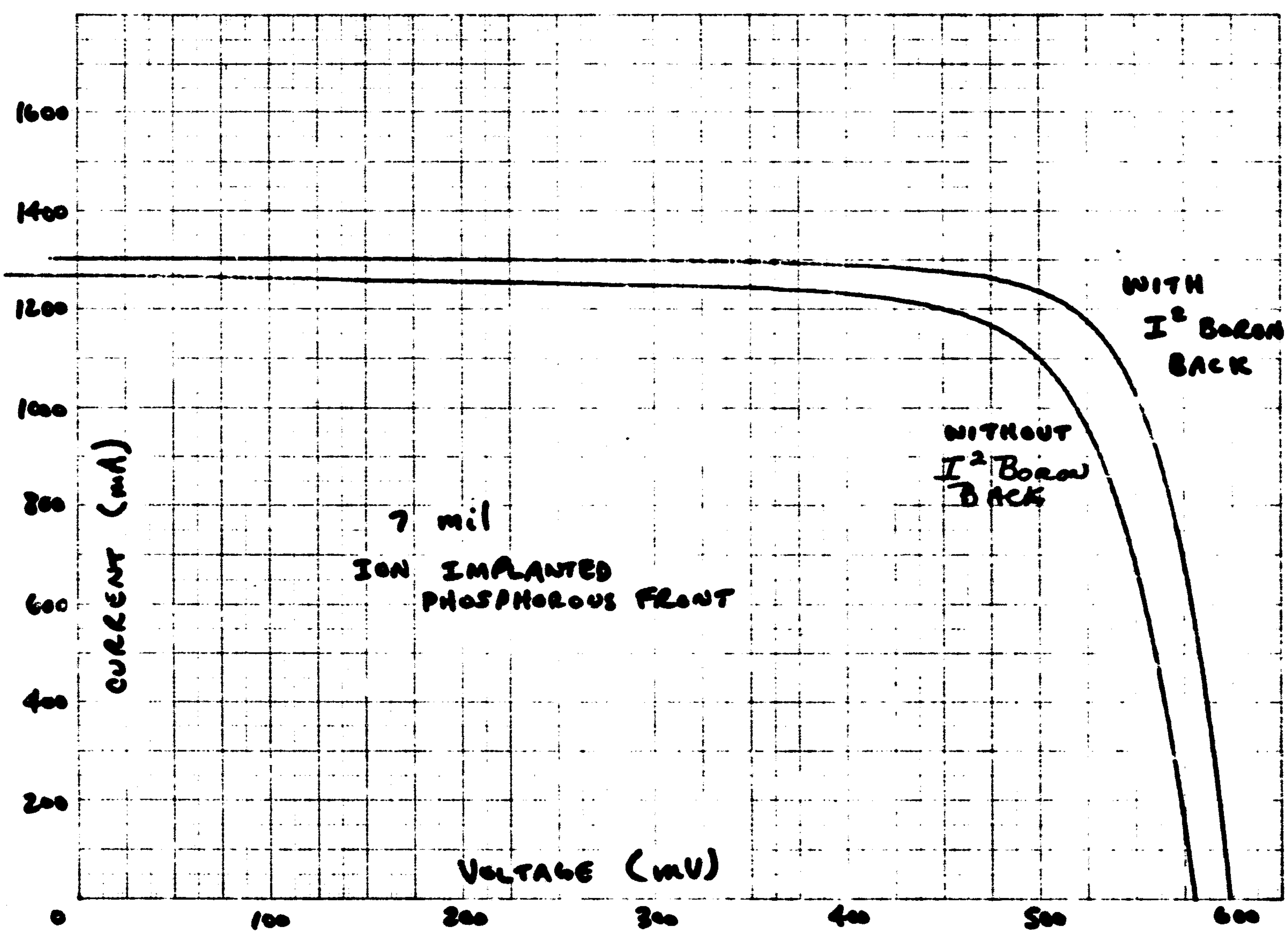


FIGURE 19: TWO CELLS FROM LOT D30: ONE WITH A BORON BACK SURFACE ENHANCEMENT FORMED BY ION IMPLANTATION (I^2) AND ONE WITHOUT.

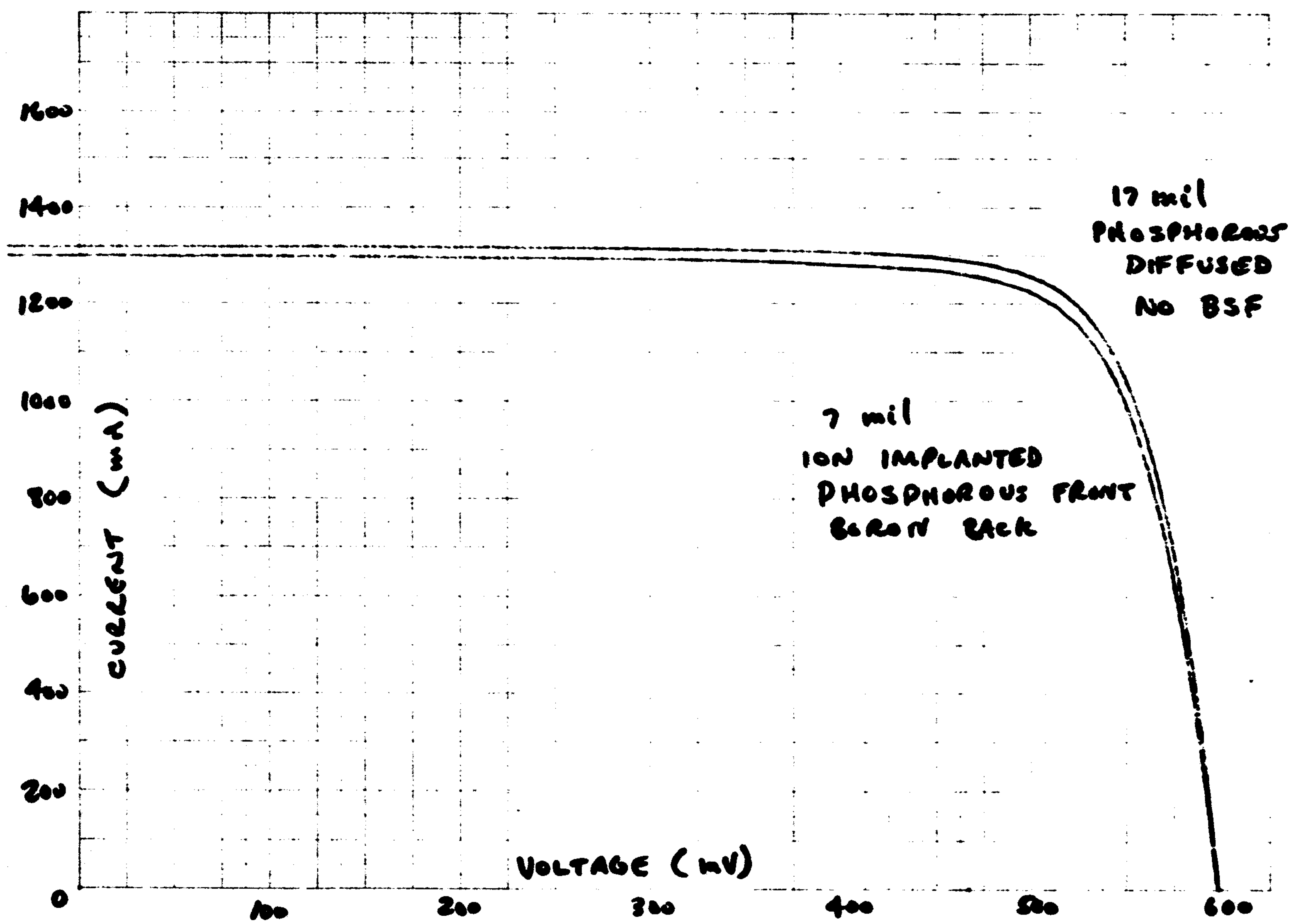


FIGURE 20: COMPARISON OF ION IMPLANTED CELL FROM LOT D30 WITH PHOSPHORUS DIFFUSED CELL FROM LOT A2.

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TABLE 22: ION IMPLANTATION PROCESS SEQUENCE USED FOR LOT D30

1. Start with 8 mil as-cut wafers which are chem-etched to 7 mils.

2. Texture both sides.

3. Implant front with phosphorus through metal mask which protects wafer perimeter. Dose: 5×10^{15} cm^{-2} Energy: 35 keV.

4. Implant back with boron.
   Dose: 5×10^{15} cm^{-2} Energy: 35 keV.

5. Anneal 30 min at 900°C in N_2.

6. Deposit LPCVD silicon nitride.

7. Anneal 60 minutes at 550°C in N_2.

8. Form ohmic pattern using photoresist to mask etching of silicon nitride.

9. Plate immersion Pd, electroless Ni, electrolytic Cu with sinter after Ni plating.

NOTE: for half the wafers in D30, step 4 was omitted so that there was no boron back surface enhancement.

TABLE 23: PILOT LINE PROCESS SPECIFICATION OUTLINE.

1. Damage etch, clean, and texture substrate.
2. Ion implant front with phosphorus, masking perimeter, and back with boron.
3. Thermal anneal and activate implanted dopant.
4. Apply silicon nitride antireflection coating.
5. Form ohmic contact pattern by etching silicon nitride.
6. Plate metal contacts using (palladium) nickel-copper system.

3.7 PILOT LINE PROCESS

This section describes the preparation, processing, and test results for a matrix of 418 substrates processed by the pilot process sequence previously outlined in Table 23. This outline will be detailed later in Section 3.7.4 and in the "Specification Process Sheets and for the Pilot Line Process" attached in the Appendix to this report.

3.7.1 DAMAGE REMOVAL REQUIREMENTS

Wafers received in the as-sawed condition must be given a surface etch to remove silicon damaged by the sawing operation. It has been assumed that, when using a wire saw, removal of 0.5 mil from each side of a wafer is sufficient to guarantee complete removal of saw damage. This was confirmed in studies cited earlier in this report when substrates were etched to thicknesses one mil less than the as-sawed thickness (from 8 mils to 7 mils, from 5 mils to 4 mils) and processed.

Recently, a technique has been developed to monitor the removal of surface damage by measuring the surface photovoltage (SPV) generated by incident monochromatic light. This has been described in an article by B. L. Sopori of the Motorola Solar R&D Labs titled "Rapid Nondestructive Techniques for Monitoring Polishing Damage in Semiconductor Wafers" to be published in Rev. Sci. Instrum., 51 (11) Nov. 1980. This article confirms that removal of 0.4 to 0.6 mil is sufficient.

A question which remains, however, is whether the texture etching process is sufficient, in itself, to remove saw damage without the necessity of a pre-texturing silicon etch. Texturing an as-sawed surface will reduce the effective wafer thickness by about 0.4 to 0.5 mil. To provide an answer to this

question, three groups of wafers from the pilot process matrix were processed without any silicon etch before texturing. These three groups (PL-5, part B; PL-9, part B; and PL-13, part B) will be described in the following sections.

3.7.2 SILICON DAMAGE-ETCH TECHNIQUE

The 418 wafers to be fabricated into solar cells with the pilot process sequence were divided into a matrix which was prepared by etching the raw substrates (received as-sawed) for various times in 15% NaOH solution at a nominal temperature of 80°C. This sodium hydroxide etching solution removes silicon damage and maintains uniformity of thickness across the diameters of the 3 inch substrates even when etching for extended periods of time.

A series of empirical tests was performed to calibrate the etch rates of the 15% NaOH solution. The data resulting from these tests are plotted in Figure 21. This figure was used to choose etch times for developing the matrix discussed in the next section.

3.7.3 PILOT PROCESS SUBSTRATE MATRIX

The 15% NaOH silicon etch discussed above was used to produce a matrix of wafers with varying amounts of initial saw damage removal and ranging in total thickness from 17.5 mils to 4.1 mils. The etching temperature ranged between 78°C and 83°C and the etch time was varied from 0 to 60 minutes. The pilot process lot matrix is given in Table 24.

There are two variables being studied with this pilot process matrix. Those lots which have etch times between zero and 6 minutes can be used to determine the required amount of saw damage removal prior to the texture etching process. As noted in Table 24, 8 minutes was chosen as the reference etch time. This time was chosen because it corresponds to removal of

FIGURE 21:

WAFER THICKNESS LOSS VERSUS ETCH TIME
FOR SAW DAMAGE REMOVAL ETCH

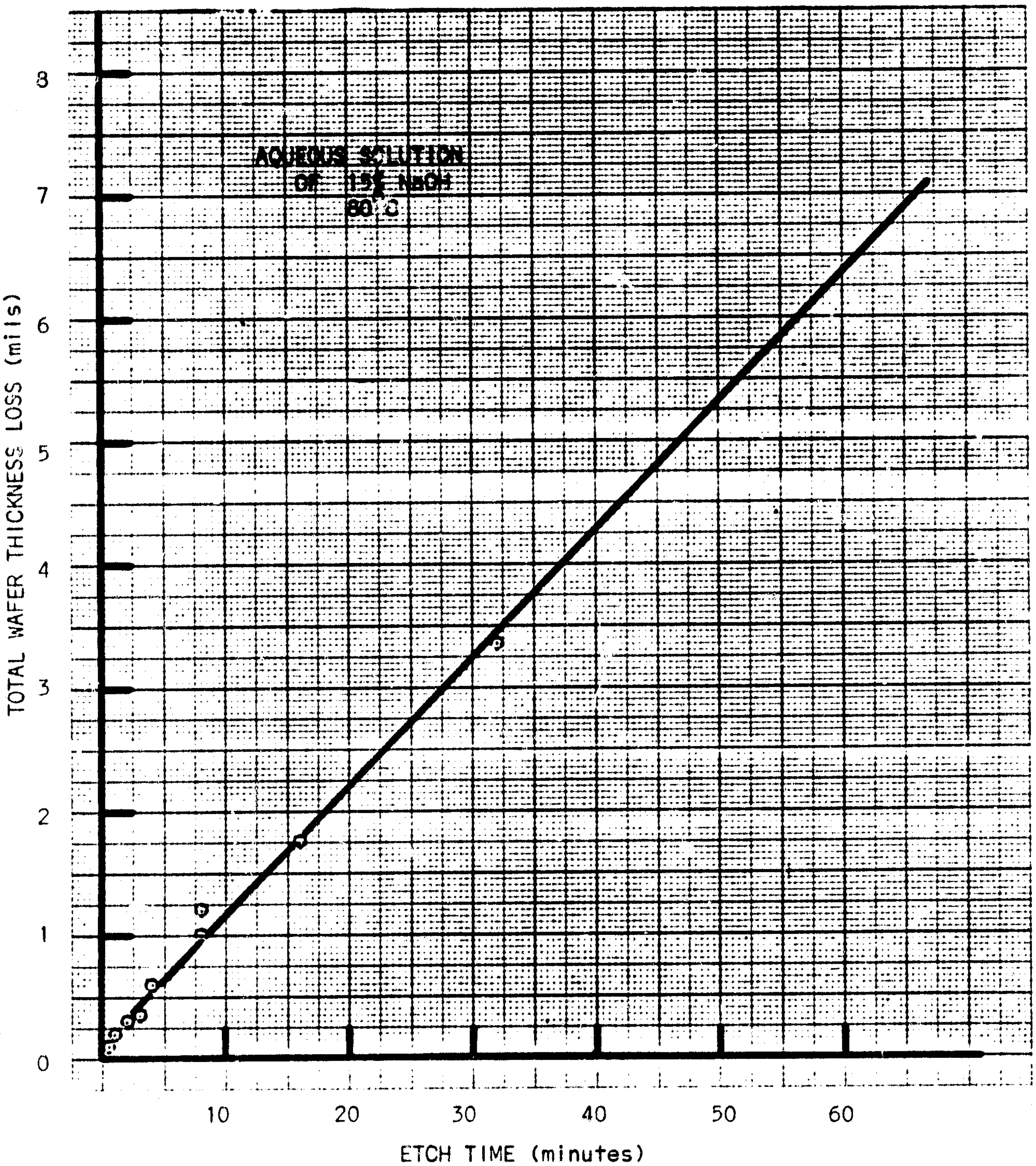


TABLE 24

PILOT PROCESS LOT IDENTIFICATION

LOT NO.	STARTING WAFER THICKNESS	DAMAGE REMOVAL ETCH TIMES* PART A	PART B
PL-2	17 mils	8 min.	2 min
PL-3	17	8	4
PL-4	17	8	6
PL-5	17	8	NONE
PL-6	17	8	20 min
PL-7	17	8	40
PL-8	17	8	60
PL-9	8 mils	8 min	NONE
PL-10	8	8	2 min
PL-11	8	8	4
PL-12	8	8	6
PL-13	8	8	NONE
PL-14	8	8	20 min
PL-15	8	8	40
PL-16	8	8	30
PL-17	8	20	20
PL-18	8	30	30
PL-19	8	40	40
PL-20	4 mils	2 min	NONE

*Damage removal etch done in 15% NaOH solution at nominally 80°C.

NOTE: Each PL lot started with 22 three inch diameter wafers, 11 in Part A and 11 in Part B.

approximately 0.5 mil of silicon from each side of the wafer or about 1.0 mil reduction in total wafer thickness. As discussed earlier, it has been experimentally determined that this is sufficient etching to guarantee complete removal of all sawing damage induced by the Motorola wire-sawing process.

The second variable being studied is the effect of wafer thickness. Starting substrates were chosen from nominally 17, 8, and 4 mil thick wafers. By etching for times from 8 to 60 minutes, the gaps between the 4, 8, and 17 mil thickness values have been bridged.

As noted in Table 24, each lot of 22 wafers is subdivided into two parts of 11 wafers each. In most instances, part A is a control group with a standard damage etch time and part B has been given a lesser or greater etch. In all cases, after the desired damage etch was performed, all lots were given identical texture etches, resulting in wafers which are textured on both sides with tetrahedral peak heights ranging from 3 to 6 micrometers.

All wafers in lots PL-2 through PL-20 were measured before processing, after damage etching, and after texture etching using an electronic, non-contact thickness gauge. Moreover, a four-point resistivity probe was used to measure the resistivity of all starting wafers. The typical standard deviation of resistivity within a lot is about 4%. The average resistivity for wafers in each lot ranged from 1.0 Ω-cm to 1.3 Ω-cm. The standard deviation of wafer thickness within a lot ranged from 0.06 mil to 0.25 mil, with 0.1 mil being a typical value.

The changes in the average wafer thickness for each part (A and B) of each lot after NaOH damage etching and after texture etching are given for reference in Table 25. When compared with the etch times from Table 24, these values can be used to update the etching calibration graph of Figure 21.

TABLE 25

CHANGE IN AVERAGE WAFER THICKNESS AFTER DAMAGE ETCHING AND AFTER TEXTURE ETCHING.

LOT NUMBER	PART A CHANGE AFTER 15% NaOH (mils)	PART A CHANGE AFTER TEXTURING (mils)	PART B CHANGE AFTER 15% NaOH (mils)	PART B CHANGE AFTER TEXTURING (mils)
PL-2	1.18	.49	0.44	.22
PL-3	1.16	.20	0.75	.42
PL-4	1.16	.16	0.88	.13
PL-5	1.15	.39	None	.55
PL-6	1.28	.39	2.78	.41
PL-7	1.20	.65	4.96	.70
PL-8	1.20	.68	7.64	.68
PL-9	1.21	.26	None	.46
PL-10	0.93	.47	0.51	.23
PL-11	1.13	.30	0.63	.30
PL-12	1.21	.25	0.97	.27
PL-13	1.14	.27	None	.47
PL-14	1.20	.31	2.42	.30
PL-15	1.15	.23	4.37	.23
PL-16	1.22	.23	3.46	.23
PL-17	2.55	.21	2.53	.23
PL-18	3.43	.25	3.41	.25
PL-19	3.82	.16	3.80	.17
PL-20	0.27	.32	None	.33

Table 26 lists the average wafer thickness for each half-lot, as processed after texture etching was completed, and the average wafer resistivity. The resistivity values are close enough to each other so that comparisons of cell performance between lots are not prevented. The given thickness values represent what the final cell thickness, exclusive of metal, should be.

3.7.4 DETAILED PROCESS SEQUENCE

For convenience, the costing sheets (SAMICS) and process specification sheets included in the Appendix are divided into ten separate operations. They are:

1) wafer slicing
2) substrate texturing
3) ion implantation
4) drive-in anneal
5) silicon nitride deposition
6) ohmic contact pattern formation
7) nickel plate
8) sinter
9) copper plate
10) cell test.

Each of these operations is specifically detailed in the Appendix, including materials consumed, equipment utilized, and process step instructions.

The first step, wafer slicing, is beyond the scope of this contract, which is to learn to utilize thin substrates. Wafers were procurred from the Motorola Materials Operation by the Solar R&D Department much as wafers would be obtained from an outside vendor. Details of the slicing operation are only available to the extent that they facilitate the costing analysis.

TABLE 26

AVERAGE WAFER THICKNESS AND RESISTIVITY FOR PILOT PROCESS LINE

LOT NUMBER	AVERAGE WAFER THICKNESS* (mils) PART A	PART B	AVERAGE WAFER RESISTIVITY (Ω-cm) PART A	PART B
PL-2	15.9	16.9	.96	.97
PL-3	16.1	16.3	1.05	1.07
PL-4	16.3	16.6	1.12	1.14
PL-5	15.9	16.9	1.22	1.22
PL-6	15.9	14.2	1.16	1.17
PL-7	15.7	11.8	1.15	1.15
PL-8	15.6	9.2	1.17	1.18
PL-9	6.8	7.8	1.08	1.08
PL-10	7.0	7.7	1.10	1.11
PL-11	6.7	7.2	1.23	1.25
PL-12	6.8	7.0	1.20	1.20
PL-13	6.8	7.8	1.10	1.10
PL-14	6.6	5.4	1.07	1.07
PL-15	7.1	3.9	1.25	1.27
PL-16	7.1	4.8	1.16	1.17
PL-17	5.8	5.8	1.15	1.15
PL-18	4.6	4.6	1.22	1.23
PL-19	4.4	4.4	1.23	1.23
PL-20	3.9	4.2	1.29	1.30

*Thickness as-processed, after texturing.

The second step, texturing, was accomplished using a standard potassium hydroxide texturing solution. Substrates were first chemically thinned in 15% NaOH for the various times listed in the pilot process matrix and then immersed in the texturing solution to texture both front and back surfaces.

Ion implantation, step 3, was accomplished with a commercially available Varion/Extrion 200 - 1000 ion implanter. Phosphorus (P^{31}) was implanted into the wafer front to form the n+-p junction, and boron (B^{11}) was implanted into the back to form a p+ enhancement layer. The phosphorus front implant was performed through a metal shadow-mask which protected the edges of the wafer, forming a planar junction. The junction area is 43.3 cm^2.

The drive-in anneal, step 4, was performed in a resistance heated tube furnace with a quartz tube liner. Wafers were inserted at low temperature and ramped up to 950°C. At that temperature the phosphorus and boron dopant atoms are activated by assuming substitutional positions in the silicon lattice. Next oxygen was injected into the furnace and the temperature was ramped down. By this method, the phosphorus junction area was oxidized to form a layer of SiO_2 about 100Å thick. This is greater than the approximately 40Å layer which can be grown on the undoped planar ring surrounding the junction. This oxide thickness difference allows differentiation of the front surface from the back surface of the solar cell after a silicon nitride layer is applied in the next step. The oxide-nitride layer over the undoped planar ring is a visually different color from the oxide-nitride layer over the phosphorus doped junctions. Otherwise, there would be no way to distinguish front from back.

Step 5, silicon nitride deposition, is accomplished with a standard low pressure chemical vapor deposition (LPCVD) silicon nitride system such as those commercially available. This results in an extremely uniform coat of Si_3N_4 on both sides of the substrate. The nitride layer is about 700Å thick and will serve as an antireflection coating as well as a dielectric which can be patterned to form an integral plating mask.

The ohmic contact pattern, step 6, is formed in the nitride by screen printing an etch resistant black wax over the nitride surface where it is to be protected from a buffered HF etch. After etching the ohmic contact openings, the wax is removed with a solvent degreaser.

Next, electroless nickel, step 7, is plated onto the exposed silicon surface. This includes the patterned ohmic grid area on the front and the entire back surface. After plating and rinsing, the cells are dried in a centrifugal drier.

Step 8, sinter, is required to assure metal contact adhesion. Heat treatment is performed in a quartz lined, resistance heated tube furnace at 250°C in a nitrogen atmosphere.

In step 9, wafers were then individually fixtured and electroplated, one at a time, in an electrolytic acid copper solution. This operation was conducted on what, today, is only a laboratory scale, but is readily envisioned to be scalable to high volume.

Finally, in step 10, cells were semi-automatically tested for open circuit voltage (V_{OC}), short circuit current (I_{SC}), and current at a preset voltage (I @ 0.47V). This process required manual positioning of cells under test but test data was automatically acquired with a Hewlett-Packard microprocessor control system.

3.7.5 PILOT PROCESS RESULTS

The results of running the nineteen lots of wafers through the process sequence given in Section 3.7.4 are summarized in the following five detailed tables.

Table 27 details the mechanical yield for each half-lot starting <u>after</u> the slicing process and ending <u>after</u> the electrical test. These yields will

TABLE 27

ACTUAL YIELDS FOR PILOT PROCESS TEST LOTS THROUGH ELECTRICAL TEST (MECHANICAL YIELD ONLY)

	PART A		PART B	
LOT NUMBER	NUMBER OF CELLS	% YIELD	NUMBER OF CELLS	% YIELD
PL-2	10	91	10	91
PL-3	11	100	11	100
PL-4	11	100	11	100
PL-5	11	100	10	91
PL-6	11	100	11	100
PL-7	9	82	8	73
PL-8	11	100	10	91
PL-9	7	64	7	64
PL-10	10	91	8	73
PL-11	9	82	9	82
PL-12	9	82	9	82
PL-13	9	82	9	82
PL-14	9	82	6	55
PL-15	9	82	6	55
PL-16	7	64	7	64
PL-17	6	55	10	91
PL-18	5	45	10	91
PL-19	7	64	6	55
PL-20	3	27	3	27

NOTE: Average wafer thicknesses for Part A and Part B of each lot are listed in Table 26, page 77.

be discussed in a later section, but as expected, thicker wafers were processed with higher yields. This was expected for this test because not enough thin substrates have as yet been processed to advance from the learning phase and develop mature process techniques. It is truly expected that at process maturity there will be only slight differences in the yields for all thicknesses studied here. Witness the results of lots PL-17, part B and PL-18, part B.

Listed in Table 28, which is continued over five pages, are the semi-automatically measured electrical test data for each cell remaining in each lot. This includes V_{OC}, I_{SC}, and I @ 0.47V. Upon reviewing these data, it is apparent that process variables must be exerting a greater overall influence on the resulting solar cell performance than are material (substrate) variables. Unfortunately, this increases the difficulty of interpreting the outcome of the pilot process tests. However, some general observations can be made and these will be formulated in the next section.

The specific data of Table 28 are summarized in two ways for each half-lot. Tables 29 and 30 present the average values (and standard deviations) of open circuit voltage and short circuit current, respectively, for each pilot process half-lot. These average values can be misleading, however. If the individual cell data are studied, it can be seen that in most cases the distributions of data for each lot are not normal distributions but are skewed toward the high values. The physical mechanisms for generating the distributions in cell performance are likely to be ones which will degrade a cell from some inherent maximum level of performance. Thus, it is likely that the performance of the better cells in each half-lot are more representative of the material capabilities than the mean values of characteristics for all the cells in each half-lot. Hence, another way of summarizing the specific cell data is presented in Table 31.

TABLE 28

CELL TEST RESULTS FOR PILOT PROCESS LOTS

	PART A			PART B		
LOT NUMBER	V_{OC} (mV)	I_{SC} (mA)	I @ .47V (mA)	V_{OC} (mV)	I_{SC} (mA)	I @ .47V (mA)
PL-2	490	940	313	545	1505	340
	400	1375	-0-	345	1465	-0-
	545	1420	348	485	1430	290
	315	1425	-0-	565	1575	835
	460	1285	-0-	370	1420	-0-
	300	1280	-0-	540	1440	330
	470	1455	-0-	355	1375	-0-
	320	1380	-0-	545	1535	330
	555	1420	338	315	1475	-0-
	490	1480	280	565	1565	840
PL-3	195	1335	-0-	440	1375	-0-
	345	1295	-0-	185	1450	-0-
	320	1340	-0-	220	1415	-0-
	335	1360	-0-	225	1120	-0-
	100	1470	-0-	410	1355	-0-
	480	1300	295	440	1320	-0-
	410	1100	-0-	485	1310	300
	475	1340	-0-	510	1360	328
	465	1345	-0-	445	1365	-0-
	490	1335	305	475	1405	-0-
	510	1365	323	425	1405	-0-
PL-4	415	1355	-0-	550	1415	350
	470	1135	-0-	530	1390	338
	535	1145	338	550	1445	343
	470	1135	-0-	525	1445	335
	530	1425	345	540	1440	338
	530	1345	340	505	1410	328
	540	1390	345	555	1365	353
	505	1410	325	505	1155	328
	535	1390	338	545	1430	345
	465	1425	-0-	500	1115	305
	550	1435	343	535	1125	345

TABLE 28 (Continued)

LOT NUMBER	PART A V_{OC} (mV)	PART A I_{SC} (mA)	PART A I @ .47V (mA)	PART B V_{OC} (mV)	PART B I_{SC} (mA)	PART B I @ .47V (mA)
PL-5	520	1145	345	360	1440	-0-
	540	1335	355	550	1465	348
	545	1240	785	570	1380	985
	530	1295	345	565	1370	970
	540	1195	353	545	1440	340
	500	1425	313	525	1170	338
	555	1325	885	545	1350	350
	560	1355	875	540	1330	348
	540	1440	340	525	1150	348
	310	1420	-0-	550	1260	885
	565	1350	983			
PL-6	550	1220	920	520	1410	333
	540	1165	348	560	1370	940
	550	1235	840	560	1330	865
	555	1330	910	565	1375	940
	545	1380	348	550	1260	823
	550	1285	848	555	1285	865
	560	1390	755	555	1290	885
	550	1255	860	560	1305	903
	570	1395	1045	545	1245	810
	575	1395	1060	560	1305	920
	570	1365	985	545	1270	785
PL-7	530	1435	335	570	1385	930
	565	1355	915	575	1420	1055
	565	1520	705	575	1380	980
	580	1375	1068	575	1380	930
	560	1545	785	560	1270	890
	575	1375	1018	565	1355	923
	570	1345	835	550	1470	338
	555	1475	343	565	1310	903
	580	1405	1130			
PL-8	560	1345	930	570	1425	1020
	555	1330	918	540	1430	343
	490	1040	305	560	1315	890
	530	1195	338	550	1210	835
	545	1165	350	535	1460	323
	540	1160	350	480	1035	288
	520	1515	310	475	1070	-0-
	460	1450	-0-	510	1060	333
	575	1385	1050	540	1320	350
	555	1495	810	540	1490	333
	575	1395	1068			

TABLE 28 (Continued)

LOT NUMBER	PART A V_{OC} (mV)	PART A I_{SC} (mA)	PART A I @ .47V (mA)	PART B V_{OC} (mV)	PART B I_{SC} (mA)	PART B I @ .47V (mA)
PL-9	540	1365	348	540	1375	348
	540	1420	348	560	1370	915
	540	1415	343	550	1365	355
	555	1365	835	560	1350	920
	540	1370	348	560	1340	878
	555	1510	810	555	1390	765
	555	1420	823	565	1355	955
PL-10	570	1330	933	565	1365	963
	560	1315	920	570	1380	1005
	555	1410	350	565	1365	1000
	570	1310	1010	545	1375	353
	570	1280	1005	570	1390	1095
	570	1295	1020	505	1525	300
	570	1280	990	555	1335	840
	565	1350	1000	570	1390	1005
	565	1365	1005			
	570	1330	1000			
PL-11	275	1320	-0-	440	1310	-0-
	270	1325	-0-	395	1310	-0-
	285	1285	-0-	475	1340	-0-
	290	1300	-0-	420	1290	-0-
	290	1295	-0-	460	1375	-0-
	325	1270	-0-	495	1355	305
	345	1275	-0-	415	1325	-0-
	310	1310	-0-	425	1320	-0-
	300	1295	-0-	410	1385	-0-
PL-12	545	1315	730	565	1140	695
	545	1330	348	560	1275	875
	550	1295	835	560	1295	928
	545	1295	710	550	1260	830
	555	1290	890	555	1295	878
	535	1360	348	560	1295	890
	555	1305	890	555	1265	755
	540	1295	700	510	1470	320
	555	1295	865	555	1315	915

TABLE 28 (Continued)

LOT NUMBER	PART A V_{OC} (mV)	PART A I_{SC} (mA)	PART A I @ .47V (mA)	PART B V_{OC} (mV)	PART B I_{SC} (mA)	PART B I @ .47V (mA)
PL-13	255	1110	-0-	195	1445	-0-
	275	1100	-0-	235	1415	-0-
	245	1245	-0-	195	1330	-0-
	280	1335	-0-	220	1260	-0-
	270	1260	-0-	210	1355	-0-
	280	1265	-0-	190	1290	-0-
	265	1300	-0-	265	1295	-0-
	245	1400	-0-	245	1275	-0-
	230	1340	-0-	215	1275	-0-
PL-14	540	1330	343	565	1140	798
	530	1305	335	545	1300	350
	440	1450	-0-	540	1305	340
	525	1285	338	540	1300	345
	545	1295	348	455	1235	-0-
	535	1300	343	470	1330	-0-
	510	1270	328			
	505	1415	318			
	450	1265	-0-			
PL-15	560	1270	990	565	1240	978
	540	1150	340	555	1235	885
	555	1250	910	565	1245	1000
	550	1250	830	560	1235	915
	560	1275	995	565	1210	1010
	560	1240	963	560	1265	915
	540	1160	330			
	560	1250	1000			
	555	1230	875			
PL-16	545	1400	350	560	1275	885
	545	1345	345	565	1300	968
	545	1300	350	555	1280	880
	545	1340	353	560	1290	920
	565	1300	935	560	1290	965
	560	1305	880	560	1275	860
	565	1280	900	555	1230	855

TABLE 28 (Continued)

LOT NUMBER	PART A V_{OC} (mV)	PART A I_{SC} (mA)	PART A I @ .47V (mA)	PART B V_{OC} (mV)	PART B I_{SC} (mA)	PART B I @ .47V (mA)
PL-17	530	1290	330	560	1315	830
	560	1290	780	575	1345	1030
	565	1320	925	570	1340	953
	540	1415	328	565	1355	950
	570	1325	903	565	1315	880
	565	1315	878	565	1315	888
				565	1335	1018
				570	1305	1020
				560	1250	850
				565	1250	940
PL-18	575	1325	1090	575	1340	1140
	575	1325	1090	575	1315	1075
	575	1330	1098	575	1315	1080
	580	1325	1093	575	1340	1025
	575	1305	1005	575	1310	1085
				580	1310	1085
				575	1325	1040
				580	1340	1110
				575	1340	1098
				570	1290	990
PL-19	575	1320	1118	565	1290	965
	570	1300	1133	565	1285	1033
	560	1255	958	570	1260	1045
	575	1310	1105	570	1305	1010
	575	1315	1060	565	1260	955
	565	1265	1000	565	1230	1018
	560	1265	940			
PL-20	575	1435	1140	580	1415	1123
	580	1375	1060	585	1405	1150
	580	1385	1060	580	1390	1085

C-2

TABLE 29

AVERAGE VALUES OF OPEN CIRCUIT VOLTAGE, V_{OC}, FOR PILOT PROCESS LOTS.

LOT NUMBER	PART A AVERAGE V_{OC} (mV)	PART A STANDARD DEVIATION (mV)	PART B AVERAGE V_{OC} (mV)	PART B STANDARD DEVIATION (mV)
PL-2	435	95	463	104
PL-3	375	132	387	118
PL-4	506	45	531	20
PL-5	519	72	528	61
PL-6	556	11	552	13
PL-7	564	16	567	9
PL-8	537	36	530	32
PL-9	546	8	556	8
PL-10	567	5	556	22
PL-11	299	24	437	33
PL-12	547	7	552	16
PL-13	261	18	219	25
PL-14	509	39	519	45
PL-15	553	8	562	4
PL-16	553	10	559	3
PL-17	555	16	566	5
PL-18	576	2	576	3
PL-19	569	7	567	3
PL-20	578	3	582	3

TABLE 30

AVERAGE VALUES OF SHORT CIRCUIT CURRENT, I_{SC}, FOR PILOT PROCESS LOTS.

LOT NUMBER	PART A AVERAGE I_{SC} (mA)	PART A STANDARD DEVIATION (mA)	PART B AVERAGE I_{SC} (mA)	PART B STANDARD DEVIATION (mA)
PL-2	1346	157	1479	66
PL-3	1326	88	1353	88
PL-4	1326	124	1340	136
PL-5	1320	95	1336	110
PL-6	1310	82	1313	52
PL-7	1426	73	1371	62
PL-8	1316	155	1282	176
PL-9	1409	51	1364	17
PL-10	1327	40	1391	57
PL-11	1297	19	1334	34
PL-12	1309	23	1290	85
PL-13	1262	101	1327	66
PL-14	1324	65	1268	70
PL-15	1231	45	1238	18
PL-16	1324	41	1277	23
PL-17	1326	46	1313	37
PL-18	1322	10	1322	17
PL-19	1290	27	1272	27
PL-20	1398	32	1403	13

TABLE 31

AVERAGE OF THE THREE HIGHEST VALUES OF V_{OC} AND I_{SC} FOR PILOT PROCESS LOTS.

LOT NUMBER	OPEN CIRCUIT VOLTAGE V_{OC} (mV) PART A	PART B	SHORT CIRCUIT CURRENT I_{SC} (mA) PART A	PART B
PL-2	530	558	1453	1558
PL-3	493	490	1398	1423
PL-4	547	552	1428	1443
PL-5	560	562	1428	1420
PL-6	572	562	1393	1385
PL-7	578	575	1513	1425
PL-8	570	560	1487	1460
PL-9	555	562	1450	1378
PL-10	570	570	1375	1435
PL-11	327	477	1318	1372
PL-12	555	562	1335	1360
PL-13	278	248	1358	1405
PL-14	540	550	1398	1312
PL-15	560	565	1265	1250
PL-16	563	562	1362	1293
PL-17	567	572	1353	1347
PL-18	577	578	1327	1340
PL-19	575	568	1315	1293
PL-20	578	582	1398	1403

Table 31 lists the average of the three highest values of V_{OC} or I_{SC} occurring in each half-lot. It can be observed that, with a few notable exceptions such as lots PL-3, PL-11, and PL-13, these average values are much more consistent from lot to lot.

3.7.6 ANALYSIS

It was originally anticipated that a cell performance trend versus thickness could be established. It is obvious that process variations have limited the extent to which this can be accomplished with the pilot process test lots. The data (average of three highest values) from Table 31 present no clear picture of firm trends. Rather, they suggest that there is little variation of cell performance parameters over the thickness range considered. These data are plotted graphically in Figure 22. There is no obvious trend in the open circuit voltage. If anything, all V_{OC} values shown may be lower than they should be for the 1.1 Ω-cm substrates processed. On the other hand, the plotted averages of short circuit current do suggest a slight trend toward lower values as cell substrates become thinner. This is to be anticipated. The decrease appears to begin for wafers thinner than 8 mils and may represent a loss of as little as 50 mA or as much as 100 mA for substrates as thin as 4 mils.

To obtain a better view of performance variations versus substrate thickness, the pilot process half lots were divided into three categories. This division is defined in Table 32. Results can now be considered as a function of three basic thicknesses, nominally 15, 7, and 4 mils for categories I, II, and III respectively.

The open circuit voltage and short circuit current for every cell in each thickness category is entered as part of a histogram in one of Figures 23 through 28. The open circuit voltage distributions for the nomina..y 15 mil

FIGURE 22

SHORT CIRCUIT CURRENT AND OPEN CIRCUIT VOLTAGE TRENDS
VERSUS WAFER THICKNESS

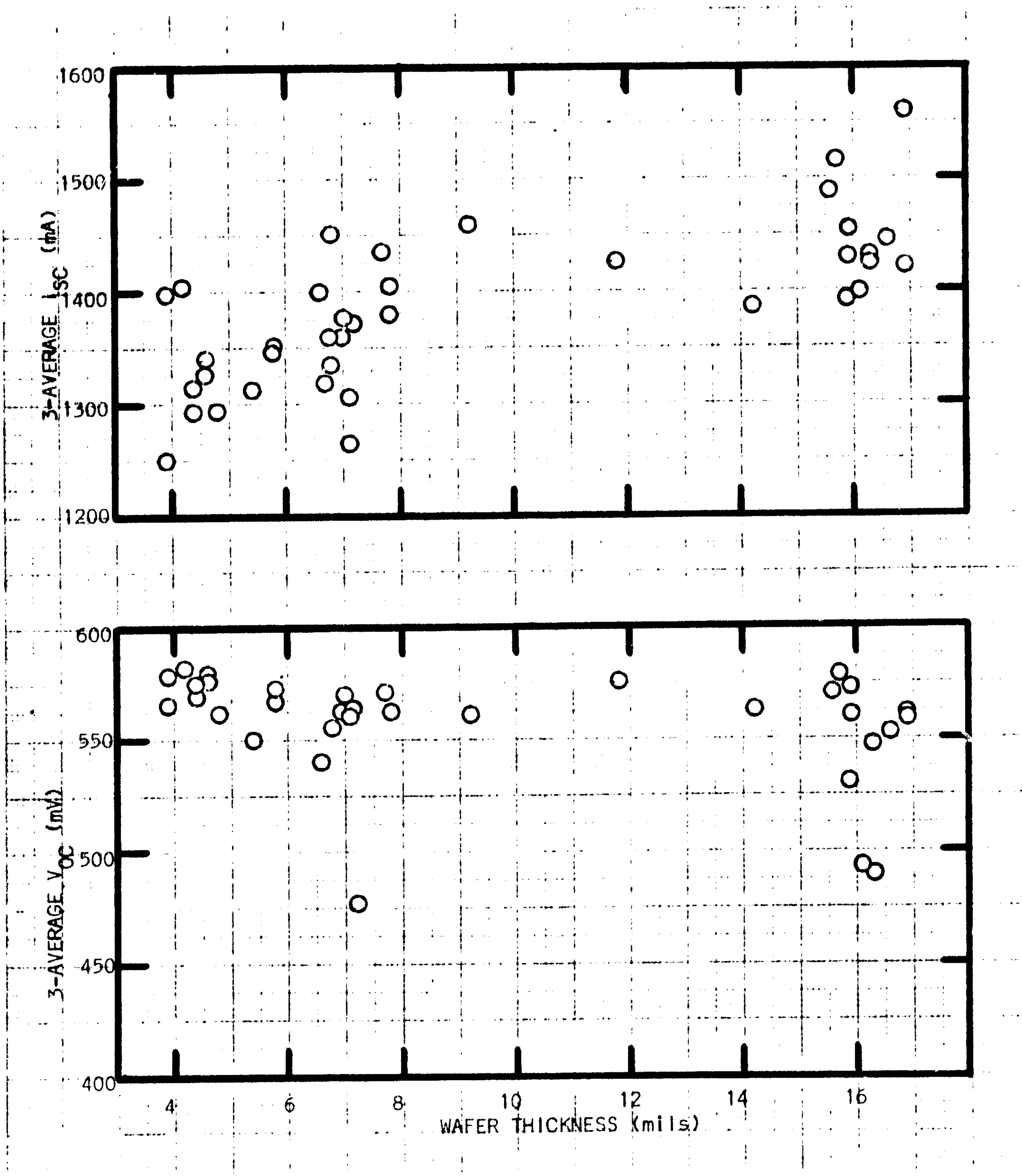


TABLE 32

DEFINITION OF THREE GENERAL CATEGORIES OF SUBSTRATE THICKNESS

LOT NUMBER	AVERAGE WAFER THICKNESS* (mils) PART A		AVERAGE WAFER THICKNESS* (mils) PART B	AVERAGE WAFER RESISTIVITY (Ω-cm) PART A		AVERAGE WAFER RESISTIVITY (Ω-cm) PART B
PL-2	15.9		16.9	.96		.97
PL-3	16.1		16.3	1.05		1.07
PL-4	16.3	I	16.6	1.12	I	1.14
PL-5	15.9		16.9	1.22		1.22
PL-6	15.9		14.2	1.16		1.17
PL-7	15.7		11.8	1.15		1.15
PL-8	15.6		9.2	1.17		1.18
PL-9	6.8		7.8	1.08		1.08
PL-10	7.0		7.7	1.10		1.11
PL-11	6.7		7.2	1.23		1.25
PL-12	6.8	II	7.0	1.20	II	1.20
PL-13	6.8		7.8	1.10		1.10
PL-14	6.6		5.4	1.07		1.07
PL-15	7.1		3.9	1.25		1.27
PL-16	7.1		4.8	1.16		1.17
PL-17	5.8		5.8	1.15		1.15
PL-18	4.6		4.6	1.22		1.23
PL-19	4.4	III	4.4	1.23	III	1.23
PL-20	3.9		4.2	1.29		1.30

THICKNESS CATEGORY			
	I	14.2 - 16.9 mils	1.12 Ω-cm
	II	6.6 - 7.8 mils	1.15 Ω-cm
	III	3.9 - 4.8 mils	1.24 Ω-cm

*Thickness as-processed, after texturing

FIGURE 23

HISTOGRAM OF CATEGORY I OPEN CIRCUIT VOLTAGE VALUES

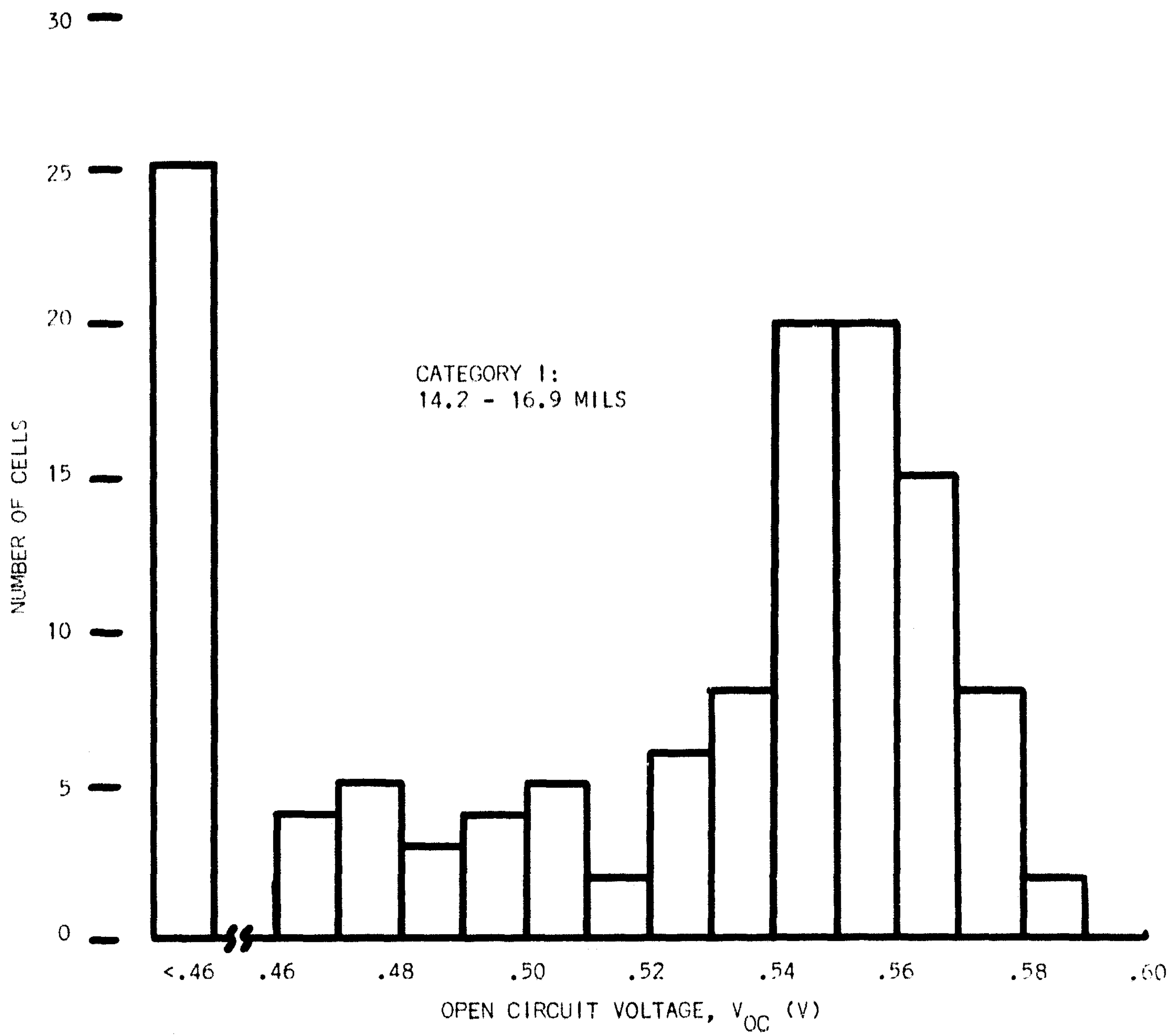


FIGURE 24

HISTOGRAM OF CATEGORY II OPEN CIRCUIT VOLTAGE VALUES

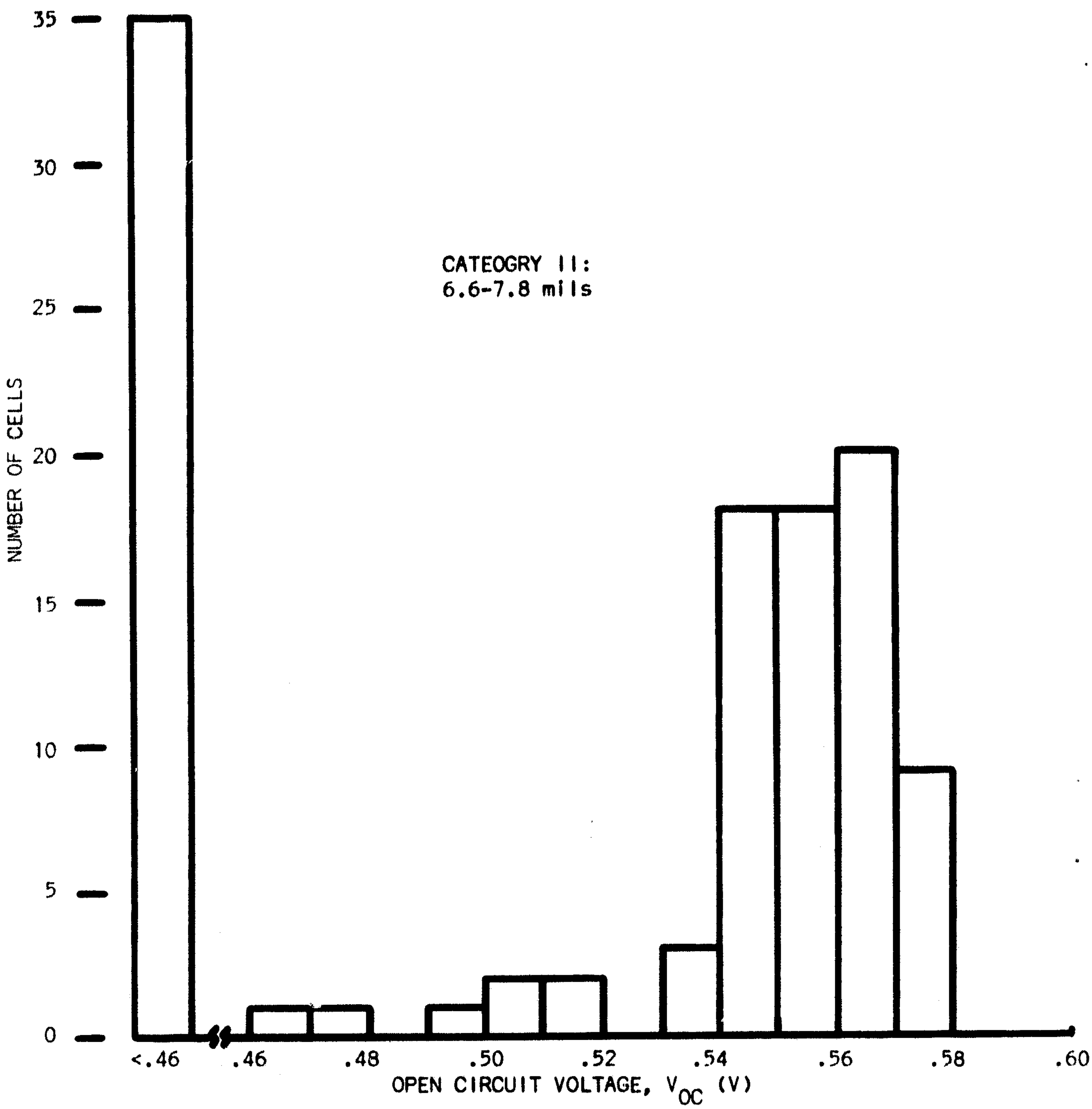


FIGURE 25

HISTOGRAM OF CATEGORY III OPEN CIRCUIT VOLTAGE VALUES

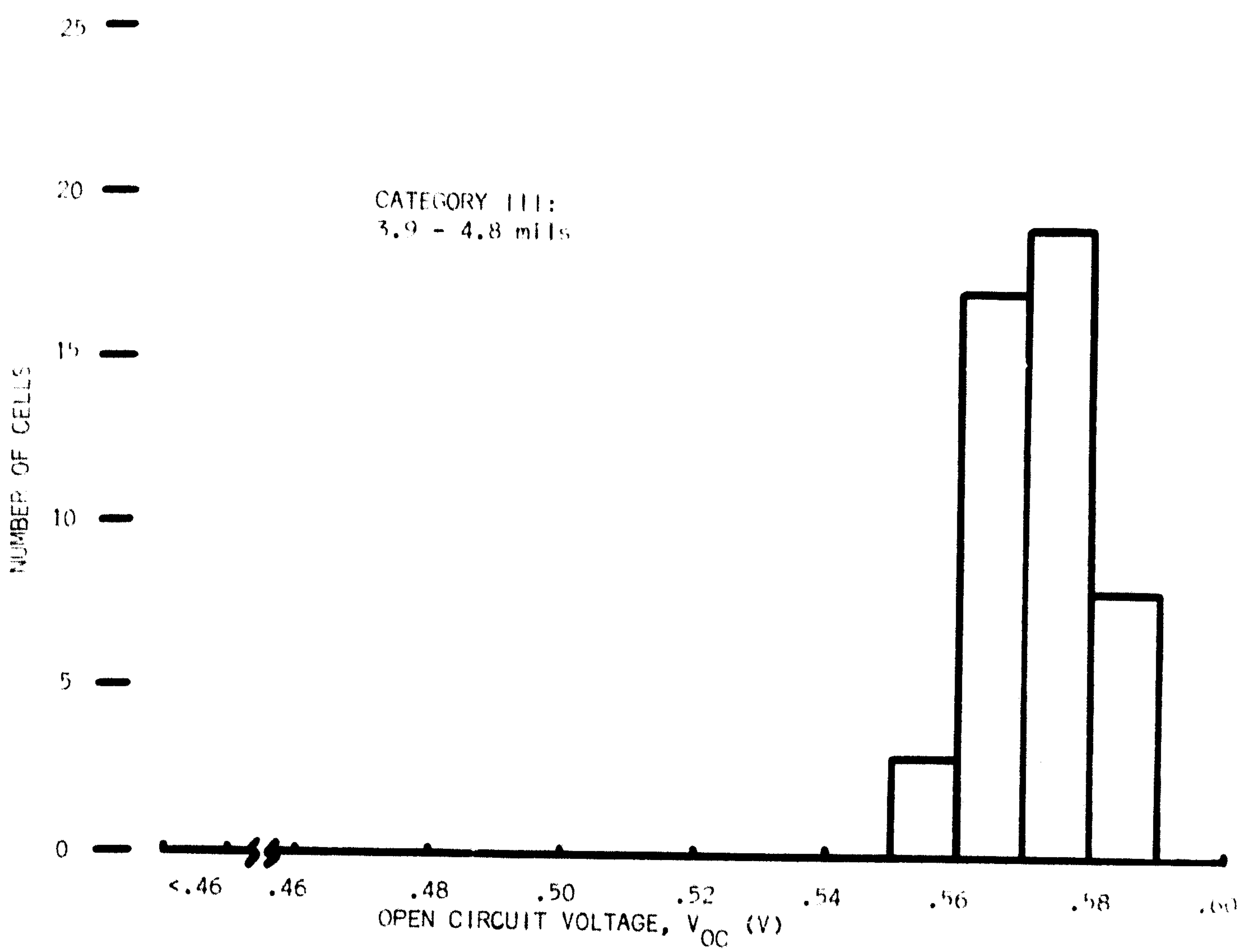


FIGURE 26

HISTOGRAM OF CATEGORY I SHORT CIRCUIT CURRENT VALUES

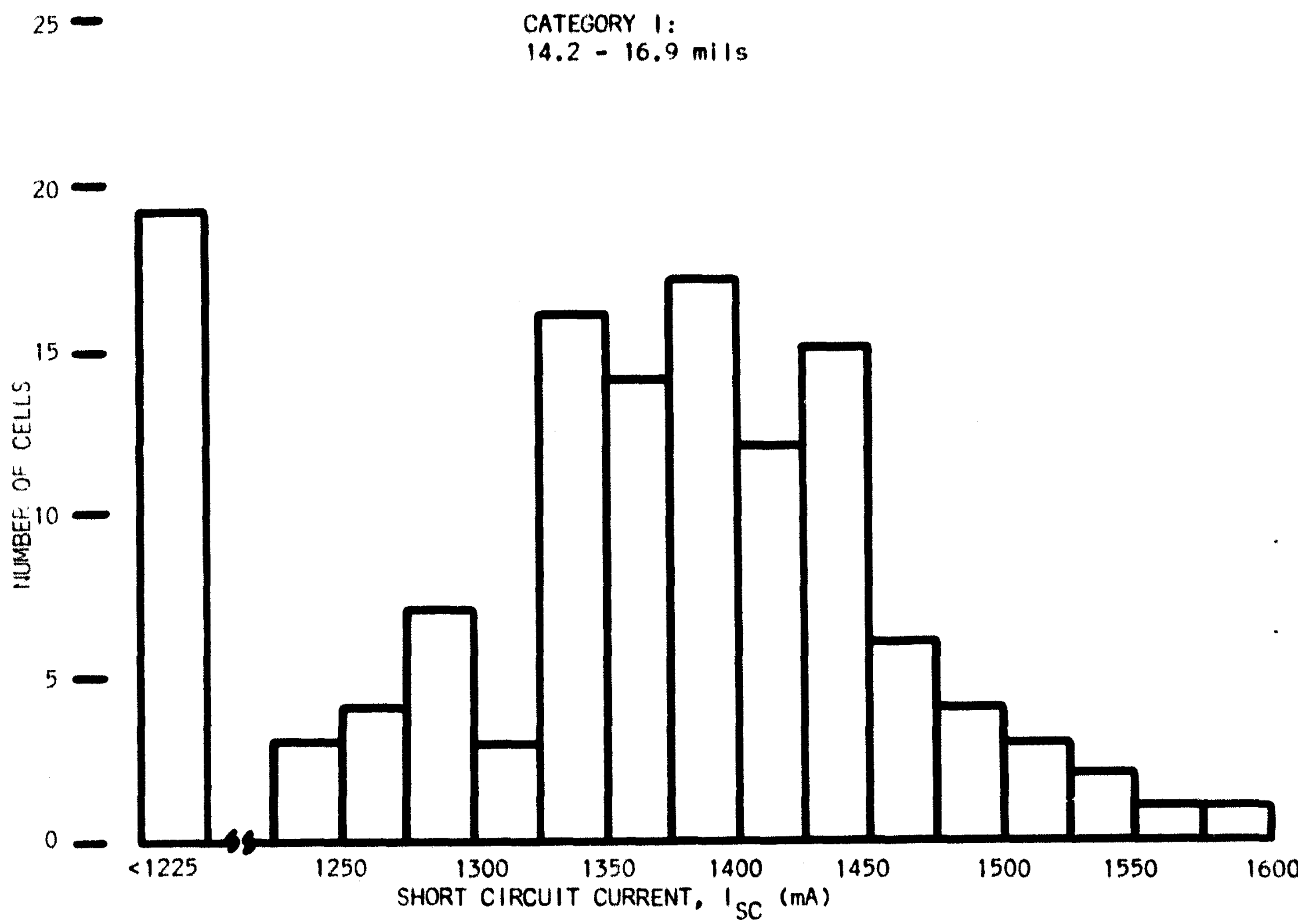


FIGURE 27

HISTOGRAM OF CATEGORY II SHORT CIRCUIT CURRENT VALUES

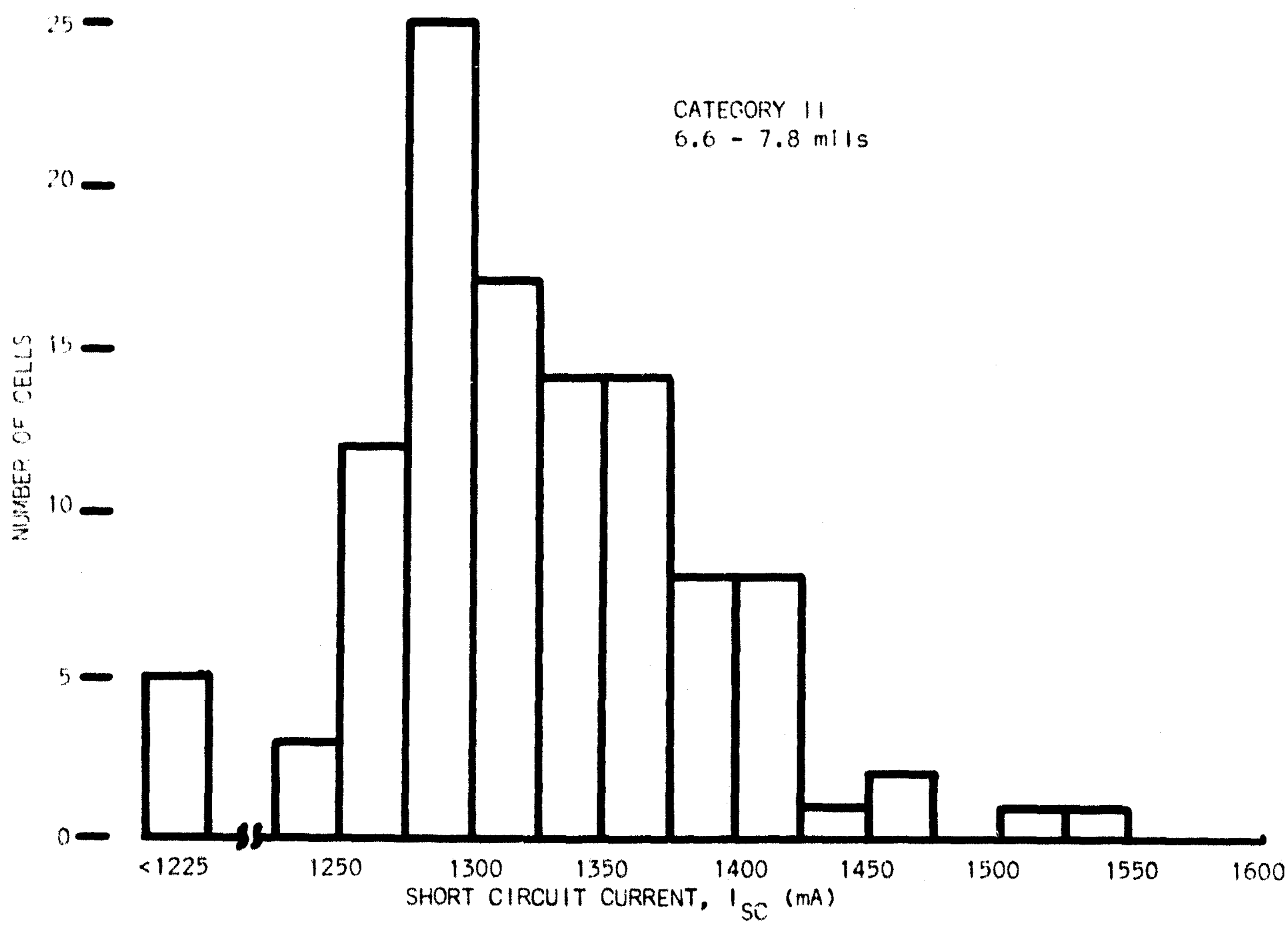
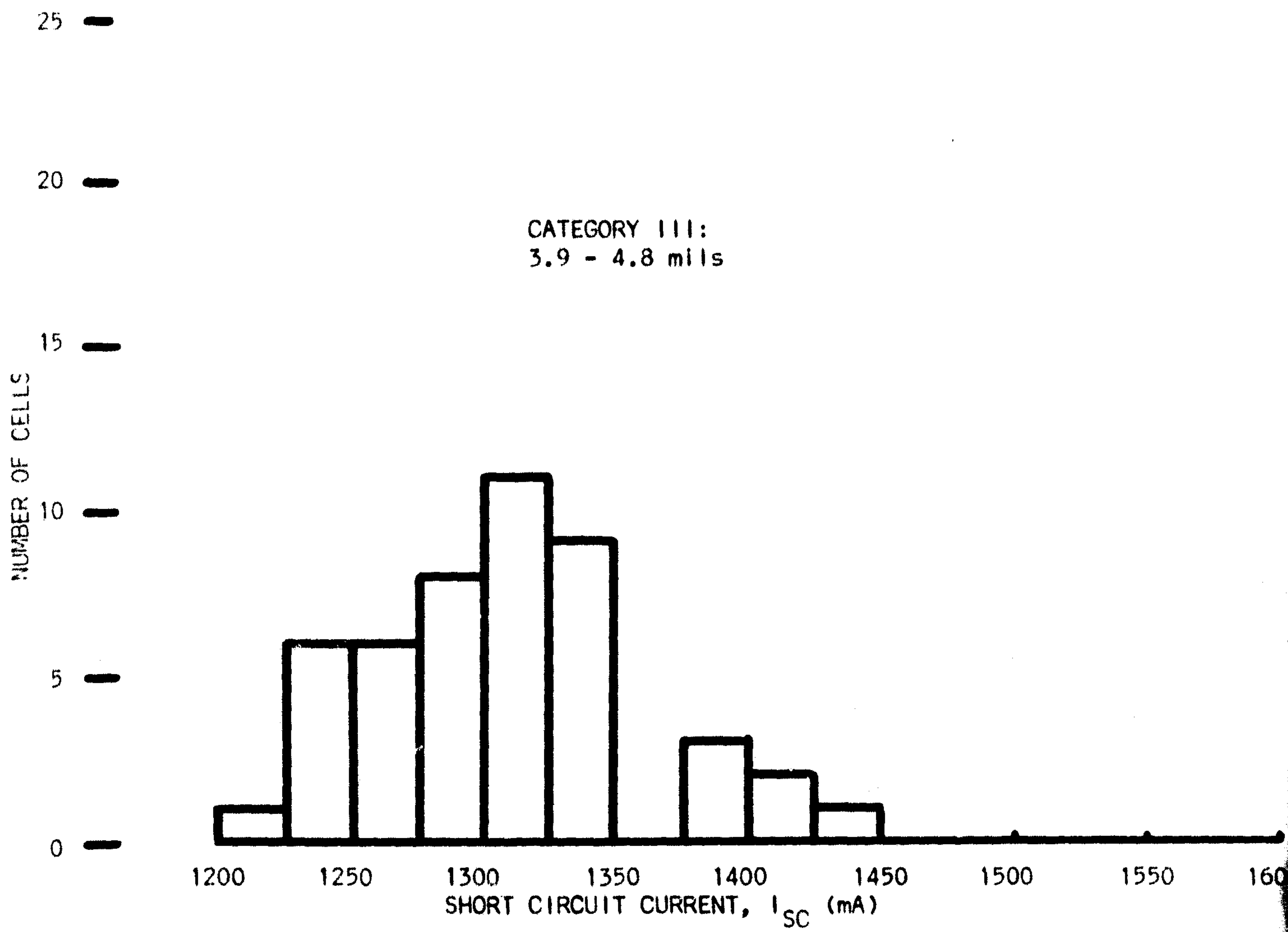


FIGURE 28

HISTOGRAM OF CATEGORY III SHORT CIRCUIT CURRENT VALUES



and 7 mil cells show the values skewed toward the high end. The voltage distributions for the 15 mil and 7 mil devices are similar, while distribution for the nominally 4 mil cells may peak about 10 mV higher. The shape of the short circuit current distributions are similar for all three categories and look to be almost normally distributed. However, both the 7 mil and 4 mil histograms seem to peak at values of about 75 mA lower than for the 15 mil cells.

4.0 CONCLUSIONS

The baseline cell process which produces a solar cell with a simple n+p structure also produces cells whose performance decreases as substrates are made thinner. This is in direct agreement with theoretical predictions. For the initial experiments performed on this contract, power output for n+p cells fabricated on 7.0 mil substrates is 96.8% that of cells on 17.4 mil substrates, and power output for cells on 4.2 mil substrates is 87.1% that of 17.4 mil cells. These losses may not be incurred if a more complex n+pp+ solar cell structure is used. However, if only the baseline cell process were considered, these power losses must be traded against the lower prices of the thinner substrates.

An IPEG price analysis has been performed for the substrate formation process. Starting with today's costs for three inch diameter Czochralski single crystal silicon ingots, and assuming wafers were sliced using a multiple-wire sawing process, it has been estimated that prices for 13 mil, 8 mil, and 5 mil as-sawed substrates should be \$2.77 per watt, \$2.33 per watt, and \$2.03 per watt, respectively.

These specific prices would indicate the relative cost savings of fabricating cells on thin substrates if the cell processing yields and cell output powers were identical for all three substrate thicknesses. Work on this contract has indicated that it is not unreasonable to assume that processing yields can be maintained for any substrate thickness down to the 4.2 mil values included in this study, once process maturity is attained.

On the other hand, cell output power will depend directly on the process sequence chosen. If the \$2.77/W 13 mil substrate is taken as reference, and if the 8 mil substrate produces a power output only 0.968 that of the 13 mil substrate, then the effective price of the 8 mil substrate is \$2.33/0.968

or \$2.41/W. If the 5 mil substrate produces a power output only 0.871 that of the 13 mil substrate, then the effective price of the 5 mil substrate is \$2.03/0.871 or \$2.33/W. The conclusion to be drawn here is that even with the use of a simple cell structure where cell power falls as the substrate is thinned, it will be cost effective to use the thinner substrates.

This cost effectiveness can be enhanced if an advanced cell structure is used to improve thin cell performance and can be fabricated for the same expense. An attempt to implement this strategy was made by choosing the pilot process sequence discussed in this report and initiating that process for 418 test wafers of varying thicknesses. By choosing ion implantation techniques, a back surface enhancement layer can be added to the cell structure with minimum complication of the process sequence. The cell test data for substrates which completed the pilot process sequence confirm, to some extent, that cell voltage can be maintained relatively independent of substrate thickness over the range of 4 to 17 mils. However, for the chosen process there is some loss of short circuit current as substrates became thinner than 7 mils. Unfortunately, it is believed that the absence of process maturity has resulted in the scattered data which has complicated the analysis. Over 400 wafers were processed through the pilot sequence, but this did not represent adequate time to complete the required learning period for handling very thin substrates and establishing process control (and thus achieve a mature pilot operation). Nevertheless, it is still concluded that the techniques embodied in the pilot process sequence specified in this report are the proper choices for efficient processing of thin substrates in the near term.

5.0 RECOMMENDATIONS

It is recommended that, for reduction of cost with today's material supply considerations, thin silicon substrates be used for fabricating solar cells. Substrates with thicknesses in the range of 7 to 8 mils should result in immediate savings with little learning time required to establish a mature production process. Substrates as thin as 4 mils would require a somewhat longer learning period but would result in further cost reductions.

Although not a central consideration of this contract, the interactive effects of ion implantation techniques and silicon substrate material parameters and structures have been observed during the course of pilot process development (and have also been reported by other participants in the JPL-LSA Project.) Since ion implantation processing can result in major simplification for advanced thin cell fabrication, it is recommended that additional studies be initiated and carried forward by the LSA Project to determine the exact physical nature of the interaciton between silicon material properties and solar cell performance when ion implantation is employed.

6.0 NEW TECHNOLOGY

No reportable items of new technology have been identified.

7.0 APPENDIX

Appended to this report are the Specification Process Sheets for the Pilot Process, as implemented during this project, and the SAMICS Cost Analysis, detailing the cost requirements as needed for implementation of the process sequence in a pilot line facility.

SECTION 7.1

SPECIFICATION PROCESS SHEETS

FOR THE

PILOT PROCESS

PILOT PROCESS SPECIFICATION

This specification details the manner in which 418 test wafers of various thicknesses were fabricated with the chosen pilot process. The basic steps of the process sequence are:

1) slice
2) texture etch
3) ion implant, n and p type
4) drive-in anneal
5) silicon nitride deposition
6) screened wax mask pattern
7) electroless nickel plate
8) metal sinter
9) electrolytic copper plate
10) cell test.

The only step which was not performed as part of this contract effort is step 1, "slice". Each of the other steps is detailed in the sheets that follow, giving lists of chemical and material supplies, lists of equipment, and detailed process step descriptions.

PROCESS STEP: TEXTURE ETCH

A. Chemical and Material Supplies - General Comments

All liquid chemicals are semiconductor, high purity grade.

All deionized water is better than 14 megohm-cm resistivity with low total organic carbon (TOC) level and is filtered at point of use.

B. Equipment - General Comments

All wet chemical processing is done at exhausted acid processing stations. Each includes essentially the following components:

Temperature controlled baths with stirring and/or recirculating filtration.

D.I. water rinse tanks with N_2 agitation.

Waste siphons

N_2 blow guns.

All work stations include the following general supplies:

Protective gloves (acid)

Protective clothing (acid)

Teflon tweezers

Teflon stir bars

Bath thermometer

Funnels

Graduated cylinders

Graduated beakers

Timers

Scales

Ph meters

Texture Etch (Continued)

C. Chemical and Material Supply list

Sodium Hydroxide, NaOH, 15%

Sulfuric Acid, H_2SO_4, 98%

Hydrofluoric Acid, HF, 49%

Hydrogen Peroxide, H_2O_2, 30%

Isopropyl Alcohol, IPA

Texture Etch Bath (Proprietary to Motorola)

Deionized (DI) Water

D. Equipment List

Exhausted acid processing stations

Wafer spin dryer

Teflon wafer carriers with handles

Quartz wafer carriers

E. Detailed process description

1. Load substrates into teflon carriers
2. Clean, H_2SO_4/10% H_2O_2, 105°C, 10 min.
3. Rinse, D.I. water, 10 min.
4. Etch, 10:1 H_2O/HF, 30 sec.
5. Rinse, D.I. water, 5 min.
6. Etch, NaOH, 15%, 100°C, time variable as desired.
7. Rinse, D.I. water, 5 min.
8. Load into quartz carrier .
9. Rinse, IPA, 10 sec.
10. Texture etch, 80°C, 60 min.
11. Rinse, D.I. water, 10 min.
12. Load into teflon carrier.
13. Spin dry, 600 RPM, 3 min (300 RPM for thin wafers).

Texture Etch (Continued)

F. Process Tolerances

All temperatures are $\pm 1^{\circ}C$, all times in minutes are ± 15 sec., all times in seconds are ± 5 sec.

PROCESS STEP: ION IMPLANT, N AND P TYPE

A. Chemical and Material Supplies - General Comments

All process gases, bottled or facility plumbed, are high purity, electronic grade with point of use filtration.

B. Chemical and Material Supply List

Phosphine, PH_3, Dopant Grade, 15% PH_3 in H_2, Matheson

Boron Trifluoride, BF_3, Dopant Grade, 100% BF_3, Matheson

C. Equipment List

Varian Extrion Ion Implanter, Model 200-1000

Cell holders, back implant.

Cell holders, front junction masked implant.

Vacuum cell pickup wand.

Gloves, lint free cloth.

D. Detailed Process Description

1. Load back implant holders
2. Implant Boron, B^{11}, $4 \times 10^{15} cm^{-2}$, 35 KeV, 1 mA max. beam
3. Load front implant holders
4. Implant Phosphorus, $4 \times 10^{15} cm^{-2}$, 35 keV, 2 mA max. beam
5. Unload holders into teflon carriers.

E. Process Tolerances

All implant parameters are controlled by the ion implanter but should remain within ±5%.

PROCESS STEP: DRIVE-IN ANNEAL

A. Chemical and Material Supplies - General Comments

All process gases, bottled or facility plumbed, are high purity, electronic grade with point of use filtration.

All deionized water is better than 14 megohm-cm resistivity with low total organic carbon (TOC) level and is filtered at point of use.

B. Equipment - General Comments

Conventional semiconductor diffusion furnaces include appropriate gas and temperature controls and quartz tubes. Also, calibration thermocouples are provided.

C. Chemical and Material Supply List

Nitrogen, N_2, facility plumbed from LN_2 source.

Oxygen, O_2, facility plumbed from LO_2 source.

Deionized (D.I.) water.

D Equipmant List

Conventional diffusion furnace, Thermco, using 130/135 mm tubes

Quartz wafer carrier

Quartz carrier transfer boat

Wafer Spin Dryer, Fluoroware Systems Corp.

D.I. water rinse bath

Teflon wafer carriers with handles

Drive-In Anneal (Continued)

4 point probe resistance meter, Veeco

Wafer groover junction depth

E. Detailed Process Description

1. Rinse, D.I. Water, 10 min.

2. Spin Dry, 600 RPM, 3 min. (300 RPM for thin wafers)

3. Load into quartz carriers

4. Drive-inn anneal, N_2; 550°C, 30 min.; ramp to 950°C - 30 min.; 950°C, O_2, 5 min.; ramp to 600°C, 130 min.

   N_2 flow is constant at 8 ℓ/min.

   O_2 flow on at 8 ℓ/min. during 5 min. cycle only.

5. Load into teflon carriers.

F. Process Tolerances

All temperatures are ±1°C, all gas flows are ±10%, all times are ±15 sec.

PROCESS STEP: SILICON NITRIDE DEPOSITION

A. Chemical and Material Supplies - General Comments

All process gases, bottled or facility plumbed, are high quality, electronic grade with point of use filtration.

All deionized water is better than 14 megohm-cm resistivity with low total organic carbon (TOC) level and is filtered at point of use.

B. Equipment - General Comments

Conventional semiconductor diffusion furnacces include appropriate gas and temperature controls and quartz tubes. Also calibration thermocouples are provided.

C. Chemical and Material Supply List

Dichlorosilane, H_2SiCl_2, 100%, Linde

Ammonia, NH_3, 100%, Linde

Nitrogen, N_2, facility plumbed fron LN_2 source

Deionized water

D. Equipment List

Conventional Diffusion Furnace, Thermco, using 130/135 mm tubes

Low pressure CVD system with gas control and vacuum system, Tylan process controller

Quartz wafer carrier

Quartz carrier transfer boat

Teflon wafer carriers

D.I. water rinse bath

Wafer Spin Dryer, Fluoroware Systems Corp.

Ellipsometer Thickness Measurement, Applied Materials

Silicon Nitride Deposition (Continued)

E. Detailed Process Description

1. Rinse, D.I. water, 10 min.

2. Spin Dry, 600 RPM, 3 min. (300 RPM for thin wafers)

3. Load into quartz carriers

4. Deposit 750Å silicon nitride, ,

   load end to pump end temperature profile: 780°C - 800°C - 820°C

   pump down <30 μm pressure, 2 min.

   N_2 purge at 400μm pressure, 5 min.

   pump down < 30μm pressure, 2 min.

   leak check < 50μm pressure, 30 sec.

   pump down < 30μm pressure, 30 sec.

   NH_3 pre-purge ≈ 400μm pressure, 30 sec.

   gas flow @ 100 cc/min.

   NH_3 and H_2SiCl_2 deposition @ 400μm pressure, 15 min.

   NH_3 flow same, H_2SiCl_2 flow @ 30 cc/min.

   NH_3 post-purge ≈ 400μm pressure, 30 sec.

   pump down < 30μm pressure, 1 min.

   N_2 purge @ 400μm pressure, 2 min.

   vent, 2 min.

5. Load into teflon wafer carriers.

F. Process Tolerances

All temperatures are ± 1°C, all gas flows are ± 10%, all times in minutes are ± 15 sec, all times in seconds are ± 5 sec.

PROCESS STEP: SCREENED WAX MASK PATTERN

A. Chemical and Material Supplies - General Comments

All liquid chemicals are semiconductor, high purity grade.

All deionized water is better than 14 megohm-cm resistivity with low total organic carbon (TOC) level and is filtered at point of use.

B. Equipment - General Comments

All wet chemical processing is done at exhausted processing stations. Each includes essentially the following components:

- Temperature controlled baths with stirring and/or recirculating filtration.
- D.I. water rinse tanks with N_2 agitation.
- Waste siphons
- N_2 blow guns.

All work stations include the following general supplies:

- Protective gloves (acid)
- Protective clothing (acid)
- Teflon tweezers
- Teflon stir bars
- Bath thermometer
- Funnels
- Graduated cylinders
- Graduated beakers
- Timers

Screened Wax Mask Pattern (Continued)

C. Chemical and Material Supply List

Black acid resist wax, Colonial ER 1095 - Fine Line.

Dichloromethane Solvent

Deionized water

Hydrofluoric Acid, HF, 49%

Ammonium Fluoride, NH_4F, 40%.

D. Equipment List

Exhausted Acid Processing Station, Integrated Air Systems

Ultrasonic Solvent Vapor Degreaser, Branson

Screen Printer, Wells Electronics, Inc.

Wafer Spin Dryer, Fluoroware Systems Corp.

Low temperature drying oven, Pacific Combustion Engineering Co.

Teflon wafer carriers with handles

Wafer drying trays

Screen printer masks

Spatulas

E. Detailed Process Description

1. Wax screen preohmic plating pattern
2. Dry wax, trays, 90°C, 15 min.
3. Load into teflon carriers
4. Etch, buffered HF, 4:1 HF:NH_4F, 45°C, 2 min.
5. Rinse, D.I. water, 5 min.
6. Spin dry, 600 RPM, 3 min. (300 RPM for thin wafers)
7. Remove wax, vapor solvent degrease, 5 min.

F. Process Tolerances

All temperatures are ± 2°C, all times are ± 15 sec.

PROCESS STEP: ELECTROLESS NICKEL PLATE

A. Chemical and Material Supplies - General Comments

All liquid chemicals are semiconductor, high purity grade.

All powdered chemicals are reagent grade.

All deionized water is better than 14 megohm-cm resistivity with low total organic carbon (TOC) level and is filtered at point of use.

B. Equipment - General Comments

All wet chemical processing is done at exhausted processing stations. Each includes essentially the following components:

Temperature controlled baths with stirring and/or recirculating filtration.

D.I. water rinse tanks with N_2 agitation.

Waste siphons

N_2 blow guns.

All work stations include the following general supplies:

Protective gloves (acid)

Protective clothing (acid)

Teflon tweezers

Teflon stir bars

Bath thermometer

Funnels

Graduated cylinders

Graduated beakers

Timers

Scales

Ph meters

Electroless Nickel Plate (Continued)

C. Chemical and Material Supply List

Electroless Nickel Plating Bath, pH 10.0 - 10.5

Nickelous Sulfate, $NiSo_4$, 25 g/ℓ

Sodium pyrophosphate, $Na_4P_2O_7$, 50 g/ℓ

Sodium hypophosphite, NaH_2PO_2, 12 g/ℓ

Ammonium Hydroxide, NH_4OH, 28% NH_3, 12 ml/ℓ

Hydrofluoric Acid, HF, 49%

Deionized water

D. Equipment List

Exhausted Acid Processing Station, Integrated Air Systems

Wafer Spin Dryer, Fluoroware Systems Corp.

Teflon wafer carriers with handles

E. Detailed Process Description

1. Etch, 50:1 H_2O/HF, 30 sec.
2. Rinse, D.I. water, 5 min.
3. Plate electroless nickel, 65°C, 5 min.
4. Rinse, D.I. water, 5 min.
5. Spin dry, 600 RPM, 3 min. (300 RPM for thin wafers).

F. Process Tolerances

All temperatures are ± 2°C, all times in minutes are ± 15 sec., all times in seconds are ± 5 sec.

PROCESS STEP: METAL SINTER

A. Chemical and Material Supplies - General Comments

All process gases, bottled or facility plumbed, are high purity, electronic grade with point of use filtration.

B. Equipment - General Comments

Conventional semiconductor diffusion furnaces include appropriate gas and temperature controls and quartz tubes. Also calibration thermocouples are provided.

C. Chemical and Material Supply List

Nitrogen, N_2, facility plumbed

D. Equipment List

Conventional Diffusion Furnace, Thermco

Quartz wafer carriers

Quartz carrier transfer boat

Teflon wafer carriers

E. Detail Process Description

1. Load wafers into quartz carriers
2. Sinter, 250°C, N_2, 60 min., flow at 10 ℓ/min.
3. Load wafers into teflon carrier .

F. Process Tolerances

All temperatures are ± 2°C, all times are ± 15 sec.

PROCESS STEP: ELECTROLYTIC COPPER PLATE

A. Chemical and Material Supplies - General Comments

All liquid chemicals are semiconductor, high purity grade.

All powdered chemicals are reagent grade.

All deionized water is better than 14 megohm-cm resistivity with low total organic carbon (TOC) level and is filtered at point of use.

B. Equipment - General Comments

All wet chemical processing is done at exhausted processing stations. Each includes essentially the following components:

Temperature controlled baths with stirring and/or recirculating filtration.

D.I. water rinse tanks with N_2 agitation.

Waste siphons

N_2 blow guns.

All work stations include the following general supplies:

Protective gloves (acid)

Protective clothing (acid)

Teflon tweezers

Teflon stir bars

Bath thermometer

Funnels

Graduated cylinders

Graduated beakers

Timers

Scales

Ph meters

Electrolytic Copper Plate (Continued)

C. Chemical and Material Supply List

Electrolytic Copper Bath

Cupric Sulfate, $CuSo_4$, 187 g/ℓ

Sulfuric Acid, H_2SO_4, 98%, 21 ml/ℓ

Current $0.05 A/cm^2$

Temperature 22°C

Electroless Nickel/Boron Bath, pH 10.0 - 10.5

Nickelous Sulfate, $NiSO_4$ 25 g/ℓ

Sodium pyrophosphate, NaP_2O_7 50 g/ℓ

Dimethylamine Borane, DMAB 39/ℓ

Ammonium Hydroxide, NH_4OH, 12 ml/ℓ

Deionized Water

Oxygen-Free Copper Electrodes

D. Equipment List

Exhausted Acid Processing Station, Integrated Air Systems

Spin Dryer, Fluoroware Systems Corp.

Electroplate wafer fixture

Teflon wafer carriers

E. Detailed Process Description

1. Plate, electrolytic Cu, R.T., 3 min.
2. Rinse, D.I. water, 5 min.
3. Plate, Electroless Ni/B, 40°C, 5 min.
4. Rinse, D.I. Water, 5 min.
5. Spin dry, 600 RPM, 3 min (300 RPM for thin wafers)

F. Process Tolerances

All temperatures are ± 2°C, all times are ± 15 sec.

PROCESS STEP: CELL TEST

A. Chemical and Material Supply List

None

B. Equipment List

Light Source and Probe Stage, ENH lamps, custom fabricated

Electronic Test Power Supply, Hewlett-Packard 6281A

Computer Processor, Hewlett-Packard 9825A

C. Detailed Process Description

1. Place cell on stage
2. Test, Automatic Sequence and Data Acquisition
3. Sort cells per data

SECTION 7.2

THE ESTABLISHMENT OF A PRODUCTION-READY MANUFACTURING PROCESS UTILIZING THIN SILICON SUBSTRATES FOR SOLAR CELLS

SAMICS COST ANALYSIS

CONTENTS:

SAMICS FORMAT A

EXPENSE ITEM ADDITION -- TEMPORARY ACCOUNT

CATALOG NUMBER	ITEM DESCRIPTION	UNIT OF MEASURE	INFLATION CLASS CODE	BASE PRICE YEAR	PRICE (DOLLARS)	REQUIRED QUANTITY
EG1000D	Saw Supplies	Unit	C	1977	0.01	1
EG1360D	Potassium Hydroxide	KG.	C	1978	3.528	1
EG5000D	Resist Wax	Gal.	C	1980	8.00	1
EG5500D	Dichloromethane Solvent.	Gal.	C	1980	3.64	1
EM1200D	Dilute Hydrofluoric Acid	Gal.	C	1979	0.063	1
EM1300D	Electroless Nickel Solution	Gal.	C	1980	1.859	1
EM1600D	Immersion Palladium-Solution	Gal.	C	1979	0.565	1
EG2100D	Electroless Copper Solution	Gal.	C	1980	9.096	1
EG2200D	Immersion Tin Solution	Gal.	C	1980	6.865	1

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FORMAT A SET I

FOR

13 MIL THICK SLICES

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr. / Pasadena, Calif. 91103

PROCESS DESCRIPTION

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMIS III computer program.

A1	Process [Referent]	SLICE-13
A2	[Descriptive Name]	SLICING OF INGOTS TO 13 MIL WAFER USING MULTIPLE WIRE SAW

PART 1 – PRODUCT DESCRIPTION

A3	[Product Referent]	WAFER-13
A4	Descriptive Name [Product Name]	THREE INCH DIAMETER, 13 MIL THICK WAFER
A5	Unit Of Measure [Product Units]	SQUARE METER

PART 2 – PROCESS CHARACTERISTICS

A6	[Output Rate] (Not Thruput)	3.71 E-3	Units (given on line A5) Per Operating Minute
A7	Average Time at Station [Processing Time]	220	Calendar Minutes (Used only to compute in-process inventory)
A8	Machine "Up" Time Fraction [Usage Fraction]	0.90	Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	SAW		
A9a	Component [Descriptive Name] (Optional)	WIRE SAW		
A10	Base Year For Equipment Prices [Price Year]	1977		
A11	Purchase Price ($ Per Component) [Purchase Cost]	30,000		
A12	Anticipated Useful Life (Years) [Useful Life]	7		
A13	[Salvage Value] ($ Per Component)	0		
A14	[Removal and Installation Cost] ($/Component)	3,000		

Note: The SAMIS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 6.0), DDB, and SL.

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) SLICE-13

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
(Facilities and Personnel Requirements)

A16 Catalog Number (Expense Item Referent)	A18 Amount Required Per Machine (Per Shift) (Amount per Machine)	A19 Units	A17 Requirement Description
A2064D	.40	SQ. FT.	MFG. SPACE (TYPE A)
B3096D	0.1	PERSON/SHIFT	SEMICONDUCTOR ASSEMBLER
B3730D	0.48	PERSON/SHIFT	MAINT. MECHANIC II

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
(Byproduct Outputs) and (Utilities and Commodities Requirements)

A20 Catalog Number (Expense Item Referent)	A22 Amount Required Per Machine Per Minute (Amount per Cycle)	A23 Units	A21 Requirement Description
C1032B	0.0083	KWH	ELECTRICITY
C1016B	0.134	CU. FT.	DOMESTIC WATER
EG1000D	5.50	UNIT	SAW SUPPLIES

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED (Required Products)

A24 (Product Reference)	A28 (Yield)* (%)	A26 (Ideal Ratio)** Of Units Out/Units In	A27 Units Of A26***	A25 Product Name
INGOT	93.0	0.812	SQ. M./KG.	THREE IN. DIA. SILICON INGOT

Prepared by R. A. PRYOR Date 2-18-81

* 100% minus percentage of required product lost.
** Assume 100% yield [illegible]
*** Examples: Modules/Cell or Cells/Wafer.

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SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

PROCESS DESCRIPTION

JET PROPULSION LABORATORY
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Note: Names given in brackets [ ] are the names of process attributes requested by the SAMIS III computer program.

A1 Process [Referent] TEXETH-13

A2 [Descriptive Name] TEXTURE ETCH AND PRE-ETCH

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] TEXSUB-13

A4 Descriptive Name [Product Name] TEXTURE ETCHED SUBSTRATE

A5 Unit Of Measure [Product Units] SUBSTRATE

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 53.0 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] 90 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] 0.93 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	TETCHER		
A9a	Component [Descriptive Name] (Optional)	TEXTURE ETCHING HOOD		
A10	Base Year For Equipment Prices [Price Year]	1978		
A11	Purchase Price ($ Per Component) [Purchase Cost]	100,000		
A12	Anticipated Useful Life (Years) [Useful Life]	8		
A13	[Salvage Value] ($ Per Component)	5,000		
A14	[Removal and Installation Cost] ($/Component)	1,500		

Note: The SAMIS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context use 0.0, (1975, 6.0), DDB, and SL.

JPL 3037-S H

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) TEXETH-13

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A2064 D	120	SQ. FT.	MFG. SPACE (TYPE A)
B3096 D	0.5	PERSON/SHIFT	SEMICONDUCTOR ASSEMBLER
B3736 D	0.05	PERSON/SHIFT	MAINT. MECHANIC II

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
C1032 B	0.05	KWH	ELECTRICITY
C2128 B	1000	CU. FT.	VENTILATION
C1144 D	0.832	CU. FT.	WATER, D.I.
EG1360 D	6.6 E-2	KG	POTASSIUM HYDROXIDE
E 1352 D	0.112	GAL	ISOPROPYL ALCOHOL
E 1600 D	0.14	LB	SODIUM HYDROXIDE

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A28 [Yield]* (%)	A26 [Ideal Ratio]** Of Units Out/Units In	A27 Units Of A26***	A25 Product Name
WAFER-13	99.4	2.193 E 2	SUBSTRATE/SQ. M.	THIRTEEN MIL WAFER

Prepared by R. A. PRYOR Date 2-18-81

* 100% minus percentage of required product lost
** Assume 100% yield here
*** Examples: Modules/Cell or C...

REVERSE SIDE JPL 3037-S R 10/78

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

PROCESS DESCRIPTION

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Note: Names given in brackets [ ] are the names of process attributes requested by the SAMIS III computer program.

A1 Process [Referent] ION-13

A2 [Descriptive Name] ION IMPLANT, N AND P TYPE

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] I-SUB-13

A4 Descriptive Name [Product Name] IMPLANTED SUBSTRATE

A5 Unit Of Measure [Product Units] SUBSTRATE

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 3.333 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] 7.5 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] 0.85 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	IMPLANTER		
A9a	Component [Descriptive Name] (Optional)	EXTRION ION IMPLANTER		
A10	Base Year For Equipment Prices [Price Year]	1980		
A11	Purchase Price ($ Per Component) [Purchase Cost]	486,000		
A12	Anticipated Useful Life (Years) [Useful Life]	8		
A13	[Salvage Value] ($ Per Component)	10,000		
A14	[Removal and Installation Cost] ($/Component)	4,000		

Note: The SAMIS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context use 0.0, (1975, 6.0), DDB, and SL.

JPL 3037-S R

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) ION-13

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
(Facilities and Personnel Requirements)

A16 Catalog Number (Expense Item Referent)	A18 Amount Required Per Machine (Per Shift) (Amount per Machine)	A19 Units	A17 Requirement Description
A2064D	200	SQ. FT.	MFG. SPACE (TYPE A)
B3096 D	1	PERSON/SHIFT	SEMICONDUCTOR ASSEMBLER
B7736 D	0.15	PERSON/SHIFT	MAINT. MECHANIC II

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
(Byproduct Outputs) and (Utilities and Commodities Requirements)

A20 Catalog Number (Expense Item Referent)	A22 Amount Required Per Machine Per Minute (Amount per Cycle)	A23 Units	A21 Requirement Description
C1032B	0.42	KWH	ELECTRICITY
C2128B	1200	CU. FT.	VENTILATION
E61460 D	7.03 E-6	CU. FT.	PHOSPHINE
E61124 D	1.23 E-5	CU. FT.	BORON TRIFLUORIDE
C1016 B	2.01	CU. FT.	DOMESTIC WATER

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED (Required Products)

A24 (Product Reference)	A28 (Yield)* (%)	A26 (Ideal Ratio)** Of Units Out/Units In	A27 Units Of A26***	A25 Product Name
TEXSUB-13	99.9	1.0	SUBSTRATE/SUBSTRATE	TEXTURE ETCHED SUBSTRATE

Prepared by R. A. PRYOR Date 2-18-81

* 100% minus percentage of required product lost

** Assume 100% yield here

*** Examples: Modules/Cell or Cells/Wafer

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SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

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4800 Oak Grove Dr. / Pasadena, Calif. 91103

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMIS III computer program.

A1 Process [Referent] DRIVE-13

A2 [Descriptive Name] DRIVE-IN DOPING REDISTRIBUTION OF IMPLANTED LAYERS

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] D-SUB-13

A4 Descriptive Name [Product Name] DOPED SUBSTRATE

A5 Unit Of Measure [Product Units] SUBSTRATE

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 96.1 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] 30 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] 0.96 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	BLT-FCE		
A9a	Component [Descriptive Name] (Optional)	BELT FURNACE		
A10	Base Year For Equipment Prices [Price Year]	1980		
A11	Purchase Price ($ Per Component) [Purchase Cost]	80,000		
A12	Anticipated Useful Life (Years) [Useful Life]	8		
A13	[Salvage Value] ($ Per Component)	4,000		
A14	[Removal and Installation Cost] ($/Component)	1,500		

Note: The SAMIS III computer program also accepts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context use 0.0, (1975, 6.0), DDB, and SL.

JPL 3037-S R1

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) DRIVE-13

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)

[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A2064D	168	SQ. FT.	MFG. SPACE (TYPE A)
B3096D	0.5	PERSON/SHIFT	SEMICONDUCTOR ASSEMBLER
B3736D	0.1	PERSON/SHIFT	MAINT. MECHANIC II

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE

[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
C1032B	0.25	KWH	ELECTRICITY
C2128B	100	CU. FT.	VENTILATION
E1416D	16.6	CU. FT.	NITROGEN

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A28 [Yield]* (%)	A26 [Ideal Ratio]** Of Units Out/Units In	A27 Units Of A26***	A25 Product Name
I-SUB-13	99.5	1.0	SUBSTRATE / SUBSTRATE	IMPLANTED SUBSTRATE

Prepared by R. A. PRYOR Date 2-18-81

* 100% minus percentage of required product lost.

** Assume 100 yield here

*** Examples: Modules/Cell or Cells/Waf

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SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

PROCESS DESCRIPTION

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Note: Names given in brackets [ ] are the names of process attributes requested by the SAMIS III computer program.

A1 Process [Referent] SI3N4-13

A2 [Descriptive Name] SILICON NITRIDE DEPOSITION

PART 1 — PRODUCT DESCRIPTION

A3 [Product Referent] AR-SUB-13

A4 Descriptive Name [Product Name] ANTIREFLECTION LAYER DEPOSITED ON SUBSTRATE

A5 Unit Of Measure [Product Units] SUBSTRATE

PART 2 — PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 16.55 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] 60 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] 0.88 Operating Minutes Per Minute

PART 3 — EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	LPCVD		
A9a	Component [Descriptive Name] (Optional)	4-TUBE LPCVD FURNACE		
A10	Base Year For Equipment Prices [Price Year]	1980		
A11	Purchase Price ($ Per Component) [Purchase Cost]	160,000		
A12	Anticipated Useful Life (Years) [Useful Life]	8		
A13	[Salvage Value] ($ Per Component)	8,000		
A14	[Removal and Installation Cost] ($/Component)	1,500		

Note: The SAMIS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context use 0.0, (1975, 6.0), DDB, and SL.

JPL 3037-S R11

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) SI 3 N 4 - 13

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel) [Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A2064 D	140	SQ. FT.	MFG. SPACE (TYPE A)
B3096 D	0.5	PERSON/SHIFT	SEMICONDUCTOR ASSEMBLER
B3776 D	0.1	PERSON/SHIFT	MAINT. MECHANIC II

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE [Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
C1032 B	1.166	KWH	ELECTRICITY
C2128 B	65	CU. FT.	VENTILATION
E1108 D	5.95 E-3	CU. FT.	AMMONIA GAS
EM 1210 D	2.824 E-3	CU. FT.	DICHLOROSILANE
E1520 D	1.524 E-2	DOLLARS	QUARTZ
E1608 D	6.095 E-3	DOLLARS	SPARE PARTS
E 1416 D	7.766 E-2	CU. FT.	NITROGEN

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A28 [Yield]* (%)	A26 [Ideal Ratio]** Of Units Out/Units In	A27 Units Of A26***	A25 Product Name
D-SUB-13	99.3	1.0	SUBSTRATE/SUBSTRATE	DOPED SUBSTRATE

Prepared by R. A. PRYOR Date 2-18-81

* 100% minus percentage of required product lost.

** A [illegible]

*** Examples [illegible]

REVERSE SIDE JPL 3037--S R 10/7[illegible]

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

PROCESS DESCRIPTION

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Note: Names given in brackets [ ] are the names of process attributes requested by the SAMIS III computer program.

A1 Process [Referent] PATRN-13

A2 [Descriptive Name] SCREENED WAX MASK PATTERN

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] P-SUB-13

A4 Descriptive Name [Product Name] PATTERNED SUBSTRATE

A5 Unit Of Measure [Product Units] SUBSTRATE

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 4.14 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] 30 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] 0.94 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	SCREENER	ETCHER	DEGRS
A9a	Component [Descriptive Name] (Optional)	SCREEN PRINTER AND BAKE	ETCH HOOD & DRYER	DEGREASER
A10	Base Year For Equipment Prices [Price Year]	1980	1980	1980
A11	Purchase Price ($ Per Component) [Purchase Cost]	10,000	7,500	7,000
A12	Anticipated Useful Life (Years) [Useful Life]	8	8	8
A13	[Salvage Value] ($ Per Component)	0	25	0
A14	[Removal and Installation Cost] ($/Component)	800	550	500

Note: The SAMIS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 6.0), DDB, and SL.

JPL 3037-S R10

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) PATRN-13

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel) [Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A2064D	144	SQ. FT.	MFG. SPACE (TYPE A)
B3096D	2	PERSON/SHIFT	SEMICONDUCTOR ASSEMBLER
B3736D	0.05	PERSON/SHIFT	MAINT. MECHANIC II

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE [Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
C1032B	0.25	KWH	ELECTRICITY
C2128B	800	CU. FT.	VENTILATION
E65000D	8.33E-4	GAL.	RESIST WAX
E65500D	1.25E-2	GAL.	DICHLOROMETHANE SOLVENT
C1144D	0.20	CU. FT.	WATER, D.I.

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A28 [Yield]* (%)	A26 [Ideal Ratio]** Of Units Out/Units In	A27 Units Of A26***	A25 Product Name
AR-SUB-13	99.4	1.0	SUBSTRATE / SUBSTRATE	AR COATED SUBSTRATE

Prepared by R.A. PRYOR Date 2-18-81

* 100% minus percentage of required product lost.

** Assume 100% yield here

*** Examples: Modules/Cell or Cells/Wafer

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SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

PROCESS DESCRIPTION

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California Institute of Technology
4800 Oak Grove Dr / Pasadena, Calif 91103

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMIS III computer program.

A1 Process [Referent] NICKEL-13

A2 [Descriptive Name] ELECTROLESS NICKEL PLATE

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] N-CELL-13

A4 Descriptive Name [Product Name] NICKEL PLATED SOLAR CELL

A5 Unit Of Measure [Product Units] CELL

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 49.8 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] 14 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] 0.958 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	NIPLATER	DRYER	REPLEN
A9a	Component [Descriptive Name] (Optional)	NICKEL PLATING HOOD	MICROWAVE DRYER	AUTO BATH REPLENISHMENT SYSTEM
A10	Base Year For Equipment Prices [Price Year]	1978	1980	1980
A11	Purchase Price ($ Per Component) [Purchase Cost]	83,260	500	5000
A12	Anticipated Useful Life (Years) [Useful Life]	8	8	8
A13	[Salvage Value] ($ Per Component)	4,163	25	250
A14	[Removal and Installation Cost] ($/Component)	1,500	50	400

Note: The SAMIS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 6.0), DDB, and SL.

JPL 3037-8 R1

Format A: Process Description (Continued)

A15 **Process Referent (From Page 1 Line A1)** NICKEL-13

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A2064D	104	SQ. FT.	MFG SPACE (TYPE A)
B3736D	0.05	PERSON/SHIFT	MAINT. MECHANIC II
B3096D	1	PERSON/SHIFT	SEMICONDUCTOR ASSEMBLER

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
C1032B	0.117	KWH	ELECTRICITY
C2128B	800	CU. FT.	VENTILATION
C1144D	0.335	CU. FT.	WATER, D.I.
EM1200D	1.32 E-2	GAL.	DILUTE HYDROFLUORIC ACID
EM1300D	3.24 E-2	GAL.	ELECTROLESS NICKEL SOLUTION

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A28 [Yield]* (%)	A26 [Ideal Ratio]** Of Units Out/Units In	A27 Units Of A26***	A25 Product Name
P-SUB-13	99.6	1.0	CELL / SUBSTRATE	PATTERNED SUBSTRATE
			/	
			/	

Prepared by R. A. PRYOR **Date** 2-18-81

* 100% minus percentage of required product lost
** Assume 100% yield here
*** Examples: Modules/Cell or C...

REVERSE SIDE JPL 3037-S R 10/78

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

PROCESS DESCRIPTION

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4800 Oak Grove Dr. / Pasadena, Calif. 91103

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMIS III computer program.

A1 Process [Referent] SINTER - 13

A2 [Descriptive Name] METAL SINTER

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] S- CELL -13

A4 Descriptive Name [Product Name] SINTERED SOLAR CELL

A5 Unit Of Measure [Product Units] CELL

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 48.05 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] 30 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] 0.96 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	BLT- FRN		
A9a	Component [Descriptive Name] (Optional)	BOLT FURNACE		
A10	Base Year For Equipment Prices [Price Year]	1980		
A11	Purchase Price ($ Per Component) [Purchase Cost]	60,000		
A12	Anticipated Useful Life (Years) [Useful Life]	8		
A13	[Salvage Value] ($ Per Component)	3,000		
A14	[Removal and Installation Cost] ($/Component)	1,500		

Note: The SAMIS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMIS context use 0.0, (1975, 6.0), DDB, and SL.

JPL 3077-S R1

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) SINTER - 13

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A2064 D	168	SQ. FT.	MFG. SPACE (TYPE A)
B7096 D	0.5	PERSON/SHIFT	SEMICONDUCTOR ASSEMBLER
B7736 D	0.1	PERSON/SHIFT	MAINT. MECHANIC II

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
C1032 B	0.25	KWH	ELECTRICITY
C 2128 B	100	CU. FT.	VENTILATION
E 1416 D	16.6	CU. FT.	NITROGEN

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A28 [Yield]* (%)	A26 [Ideal Ratio]** Of Units Out/Units In	A27 Units Of A26***	A25 Product Name
N-CELL-13	99.9	1.0	CELL / CELL	NI PLATED SOLAR CELL

Prepared by R. A. PRYOR Date 2-18-81

* 100% minus percentage of required product lost

** Assume 100% yield here

*** Examples: Modules/Cell or Cells/...

REVERSE SIDE JPL 5037-S R 10/78

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr. / Pasadena, Calif. 91103

PROCESS DESCRIPTION

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMIS III computer program.

A1 Process [Referent] COPPER - 13

A2 [Descriptive Name] ELECTROLESS COPPER PLATE

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] C - CELL - 13

A4 Descriptive Name [Product Name] COPPER PLATED SOLAR CELL WITH PROTECTIVE CAP

A5 Unit Of Measure [Product Units] CELL

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 24.90 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] 101 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] 0.94 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS (Machine Description)

A9	Component [Referent]	CUPLATER	DRYER	REPLEN
A9a	Component [Descriptive Name] (Optional)	COPPER PLATING HOOD	MICROWAVE DRYER	AUTO BATH REPLENISHMENT SYSTEM
A10	Base Year For Equipment Prices [Price Year]	1980	1980	1980
A11	Purchase Price ($ Per Component) [Purchase Cost]	90,000	500	10,000
A12	Anticipated Useful Life (Years) [Useful Life]	8	8	8
A13	[Salvage Value] ($ Per Component)	4,500	25	500
A14	[Removal and Installation Cost] ($/Component)	1,500	50	400

Note: The SAMIS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context use 0.0, (1975, 6.0), DDB, and SL.

JPL 3037-S R10

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) COPPER - 13

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A2064D	156	SQ. FT.	MFG. SPACE (TYPE A)
B3736D	6 E-2	PERSON/SHIFT	MAINT. MECHANIC II
B3096D	0.5	PERSON/SHIFT	SEMICONDUCTOR ASSEMBLER

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
C1032B	0.35	KWH	ELECTRICITY
C2128B	800	CU. FT.	VENTILATION
C1144D	0.535	CU. FT.	WATER, D.I.
E62100D	2.21 E-2	GAL.	ELECTROLESS COPPER SOLUTION
E62200D	6.6 E-3	GAL.	IMMERSION TIN SOLUTION

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A28 [Yield]* (%)	A26 [Ideal Ratio]** Of Units Out/Units In	A27 Units Of A26***	A25 Product Name
S-CELL-13	99.6	1.0	CELL / CELL	SINTERED SOLAR CELL

Prepared by R. A. PRYOR Date 2-18-81

* 100% minus percentage of required product lost
** Assume 100% yield here
*** Examples, Modules/Cell or Cell/Wafer

REVERSE SIDE JPL 3037-S R 10/78

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SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

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California Institute of Technology
4800 Oak Grove Dr / Pasadena, Calif 91103

PROCESS DESCRIPTION

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMIS III computer program.

A1 Process [Referent] CELTST-13

A2 [Descriptive Name] ELECTRICAL TEST OF SOLAR CELLS

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] T-CELL-13

A4 Descriptive Name [Product Name] TESTED SOLAR CELL

A5 Unit Of Measure [Product Units] CELL

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 18.8 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] 0.15 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] 0.95 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	CTESTER		
A9a	Component [Descriptive Name] (Optional)	SOLAR CELL TESTER		
A10	Base Year For Equipment Prices [Price Year]	1980		
A11	Purchase Price ($ Per Component) [Purchase Cost]	46,000		
A12	Anticipated Useful Life (Years) [Useful Life]	8		
A13	[Salvage Value] ($ Per Component)	2,300		
A14	[Removal and Installation Cost] ($/Component)	400		

Note: The SAMIS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 6.0), DDB, and SL.

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) CEL TST - 13

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A2664D	60	SQ. FT.	MFG. SPACE (TYPE A)
B3096D	0.667	PERSON/SHIFT	SEMICONDUCTOR ASSEMBLER
B3688D	5E-2	PERSON/SHIFT	ELECTRONICS MAINT. MAN

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
C1032B	2.5E-2	KWH	ELECTRICITY

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A28 [Yield]* (%)	A26 [Ideal Ratio]** Of Units Out/Units In	A27 Units Of A26***	A25 Product Name
C-CELL-13	94.0	1.0	CELL/CELL	CU PLATED SOLAR CELL

Prepared by R. A. PRYOR Date 7-23-80

* 100% minus percentage of required product lost.
** As[illegible]
*** Examples. Module/Cell or Cell/Wafer.

REVERSE SIDE JPL 3037-S R 10/78

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FORMAT A SET II

FOR

8 MIL THICK SLICES

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

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California Institute of Technology
4800 Oak Grove Dr / Pasadena, Calif 91103

PROCESS DESCRIPTION

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMIS III computer program.

A1 Process [Referent] SLICE-8

A2 [Descriptive Name] SLICING OF INGOTS TO 8 MIL WAFERS USING MULTIPLE WIRE SAW

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] WAFER-8

A4 Descriptive Name [Product Name] THREE INCH DIAMETER, 8 MIL THICK WAFER

A5 Unit Of Measure [Product Units] SQUARE METER

PART 2 – PROCESS CHARACTERISTICS

A6	[Output Rate] (Not Thruput)	4.46 E-3	Units (given on line A5) Per Operating Minute
A7	Average Time at Station [Processing Time]	220	Calendar Minutes (Used only to compute in-process inventory)
A8	Machine "Up" Time Fraction [Usage Fraction]	0.90	Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	SAW		
A9a	Component [Descriptive Name] (Optional)	WIRE SAW		
A10	Base Year For Equipment Prices [Price Year]	1977		
A11	Purchase Price ($ Per Component) [Purchase Cost]	30,000		
A12	Anticipated Useful Life (Years) [Useful Life]	7		
A13	[Salvage Value] ($ Per Component)	0		
A14	[Removal and Installation Cost] ($/Component)	3,000		

Note: The SAMIS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. [illegible] SAMICS contract use 0.0, (1975, 6.0), DDB, and SL.

JPL 5037-S [illegible]

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) SLICE-8

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A2064D	40	SQ. FT.	MFG. SPACE (TYPE A)
B3096D	0.1	PERSON/SHIFT	SEMICONDUCTOR ASSEMBLER
B3736D	0.48	PERSON/SHIFT	MAINT. MECHANIC II

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
C1032B	0.0083	KWH	ELECTRICITY
C1016B	0.134	CU. FT.	DOMESTIC WATER
E61000D	2.24	UNIT	SAW SUPPLIES

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A28 [Yield]* (%)	A26 [Ideal Ratio]** Of Units Out/Units In	A27 Units Of A26***	A25 Product Name
INGOT	85.0	1.069	SQ. M./KG.	THREE IN. DIA. SILICON INGOT

Prepared by R. A. PRYOR Date 2-18-81

* 100% minus percentage of required product lost

** Assume 100% yield here

*** Examples: Modules/Cell or Cells/Wafer.

REVERSE SIDE JPL 3037-8 R 10/78

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

PROCESS DESCRIPTION

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Note: Names given in brackets [ ] are the names of process attributes requested by the SAMIS III computer program.

A1 Process [Referent] TEKETH-8

A2 [Descriptive Name] TEXTURE ETCH AND PRE-ETCH

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] TEXSUB-8

A4 Descriptive Name [Product Name] TEXTURE ETCHED SUBSTRATE

A5 Unit Of Measure [Product Units] SUBSTRATE

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 52.9 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] 90 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] 0.93 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	TETCHER		
A9a	Component [Descriptive Name] (Optional)	TEXTURE ETCHING HOOD		
A10	Base Year For Equipment Prices [Price Year]	1978		
A11	Purchase Price ($ Per Component) [Purchase Cost]	100,000		
A12	Anticipated Useful Life (Years) [Useful Life]	8		
A13	[Salvage Value] ($ Per Component)	5,000		
A14	[Removal and Installation Cost] ($/Component)	1,500		

Note: The SAMIS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the [illegible] use 0.0, (1975, 6.0), DDB, and SL.

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JPL 3037-S R1

Format A: Process Description (Continued)

A15 **Process Referent (From Page 1 Line A1)** TEXETH-8

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A2064D	120	SQ. FT.	MFG. SPACE (TYPE A)
B7096D	0.5	PERSON/SHIFT	SEMICONDUCTOR ASSEMBLER
B7736D	0.05	PERSON/SHIFT	MAINT. MECHANIC II

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
C1032B	0.05	KWH	ELECTRICITY
C2128B	1000	CU. FT.	VENTILATION
C1144D	0.832	CU. FT.	WATER, D.I.
E61360D	6.6 E-2	KG	POTASSIUM HYDROXIDE
E1352D	0.112	GAL	ISOPROPYL ALCOHOL
E1600D	0.14	LB	SODIUM HYDROXIDE

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A28 [Yield]* (%)	A26 [Ideal Ratio]** Of Units Out/Units In	A27 Units Of A26***	A25 Product Name
WAFER-8	99.2	2.173E2	SUBSTRATE / SQ. M.	EIGHT MIL WAFER

Prepared by R. A. PRYOR **Date** 2-18-81

* 100% minus percentage of required product lost
** Assume 100% yield here
*** Examples: Modules/Cell or Cells/[illegible]

REVERSE SIDE JPL 3037-8 R 10/78

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

PROCESS DESCRIPTION

JET PROPULSION LABORATORY
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4800 Oak Grove Dr / Pasadena, Calif 91103

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMIS III computer program.

A1 Process [Referent] ION-8

A2 [Descriptive Name] ION IMPLANT, N AND P TYPE

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] I-SUB-8

A4 Descriptive Name [Product Name] IMPLANTED SUBSTRATE

A5 Unit Of Measure [Product Units] SUBSTRATE

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 3.330 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] 7.5 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] 0.85 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	IMPLANTER		
A9a	Component [Descriptive Name] (Optional)	EXTRION ION IMPLANTER		
A10	Base Year For Equipment Prices [Price Year]	1980		
A11	Purchase Price ($ Per Component) [Purchase Cost]	486,000		
A12	Anticipated Useful Life (Years) [Useful Life]	8		
A13	[Salvage Value] ($ Per Component)	10,000		
A14	[Removal and Installation Cost] ($/Component)	4,000		

Note: The SAMIS III computer program also provides for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the JPL SAMICS context use 0.0, (1975, 6.0), DDB, and SL.

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) 10N-8

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A2064D	200	SQ. FT.	MFG. SPACE (TYPE A)
B3096D	1	PERSON/SHIFT	SEMICONDUCTOR ASSEMBLER
B3736D	0.15	PERSON/SHIFT	MAINT. MECHANIC II

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
C1032B	0.42	KWH	ELECTRICITY
C2128B	1200	CU. FT.	VENTILATION
E61460D	7.03E-6	CU. FT.	PHOSPHINE
E61124D	1.23E-5	CU. FT.	BORON TRIFLUORIDE
C1016B	2.01	CU. FT.	DOMESTIC WATER

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A28 [Yield]* (%)	A26 [Ideal Ratio]** Of Units Out/Units In	A27 Units Of A26***	A25 Product Name
TEXSUB-8	99.8	1.0	SUBSTRATE/SUBSTRATE	TEXTURE ETCHED SUBSTRATE

Prepared by R.A. PRYOR Date 2-18-81

* 100% minus percentage of required product lost.
** Assume 100% yield here
*** Examples: Modules/Cell or Cells/Wafer

REVERSE SIDE JPL 3037-S R 10/78

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

PROCESS DESCRIPTION

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4800 Oak Grove Dr / Pasadena, Calif 91103

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMIS III computer program.

A1 Process [Referent] DRIVE-8

A2 [Descriptive Name] DRIVE-IN DOPING REDISTRIBUTION OF IMPLANTED LAYERS

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] D-SUB-8

A4 Descriptive Name [Product Name] DOPED SUBSTRATE

A5 Unit Of Measure [Product Units] SUBSTRATE

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 96.0 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] 30 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] 0.96 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	BLT-FCE		
A9a	Component [Descriptive Name] (Optional)	BELT FURNACE		
A10	Base Year For Equipment Prices [Price Year]	1980		
A11	Purchase Price ($ Per Component) [Purchase Cost]	80000		
A12	Anticipated Useful Life (Years) [Useful Life]	8		
A13	[Salvage Value] ($ Per Component)	4,000		
A14	[Removal and Installation Cost] ($/Component)	1,500		

Note: The SAMIS III computer program [illegible] for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], [illegible] equipment book depreciation method]. In the USA SAMICS context use 0.0, (1975, 6.0), DDB, and SL.

JPL 3037-S R!

Format A: Process Description (Continued)

A15 **Process Referent (From Page 1 Line A1)** DRIVE- 8

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A2064D	168	SQ. FT.	MFG. SPACE (TYPE A)
B3096D	0.5	PERSON/SHIFT	SEMICONDUCTOR ASSEMBLER
B3736D	0.1	PERSON/SHIFT	MAINT. MECHANIC II

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
C1032B	0.25	KWH	ELECTRICITY
C2128B	100	CU. FT.	VENTILATION
E1416D	16.6	CU. FT.	NITROGEN

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A28 [Yield]* (%)	A26 [Ideal Ratio]** Of Units Out/Units In	A27 Units Of A26***	A25 Product Name
I-SUB-8	99.4	1.0	SUBSTRATE / SUBSTRATE	IMPLANTED SUBSTRATE

Prepared by R. A. PRYOR **Date** 2-18-81

* 100% minus percentage of required product lost.
** Assume 100% yield here
*** Examples: Modules/Cell or Cells/Wafer

REVERSE SIDE JPL 3037-8 R 10/78

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

PROCESS DESCRIPTION

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4800 Oak Grove Dr / Pasadena, Calif 91103

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMIS III computer program.

A1 Process [Referent] SI3N4-8

A2 [Descriptive Name] SILICON NITRIDE DEPOSITION

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] AR-SUB-8

A4 Descriptive Name [Product Name] ANTIREFLECTION LAYER DEPOSITED ON SUBSTRATE

A5 Unit Of Measure [Product Units] SUBSTRATE

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 16.53 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] 60 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] 0.88 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	LPCVD		
A9a	Component [Descriptive Name] (Optional)	4-TUBE LPCVD FURNACE		
A10	Base Year For Equipment Prices [Price Year]	1980		
A11	Purchase Price ($ Per Component) [Purchase Cost]	160,000		
A12	Anticipated Useful Life (Years) [Useful Life]	8		
A13	[Salvage Value] ($ Per Component)	8,000		
A14	[Removal and Installation Cost] ($/Component)	1,500		

Note: The SAMIS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context use 0.0, (1975, 6.0), DDB, and SL.

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Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) SI 3N4 - 8

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel) [Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A2064D	140	SQ. FT.	MFG. SPACE (TYPE A)
B3096 D	0.5	PERSON/SHIFT	SEMICONDUCTOR ASSEMBLER
B3776 D	0.1	PERSON/SHIFT	MAINT. MECHANIC II

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE [Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
C1032B	1.166	KWH	ELECTRICITY
C2128B	65	CU. FT.	VENTILATION
E1108D	5.95 E-3	CU. FT.	AMMONIA GAS
EM 1210 D	2.824 E-3	CU. FT.	DICHLOROSILANE
E1520 D	1.524E-2	DOLLARS	QUARTZ
E1608 D	6.095 E-3	DOLLARS	SPARE PARTS
E 1416 D	7.766 E-2	CU. FT.	NITROGEN

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A28 [Yield]* (%)	A26 [Ideal Ratio]** Of Units Out/Units In	A27 Units Of A26***	A25 Product Name
D-SUB-8	99.2	1.0	SUBSTRATE/SUBSTRATE	DOPED SUBSTRATE

Prepared by R. A. PRYOR Date 2-18-81

* 100% minus percentage of required product lost

** Assume 100% yield here

*** Examples: Module/Cell or Cell/Wafer

REVERSE SIDE JPL 3037-S R 10/78

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

PROCESS DESCRIPTION

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California Institute of Technology
4800 Oak Grove Dr / Pasadena, Calif 91103

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMIS III computer program.

A1 Process [Referent] PATRN-8

A2 [Descriptive Name] SCREENED WAX MASK PATTERN

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] P-SUB-8

A4 Descriptive Name [Product Name] PATTERNED SUBSTRATE

A5 Unit Of Measure [Product Units] SUBSTRATE

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 4.13 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] 30 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] 0.94 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	SCREENER	ETCHER	DEGRS
A9a	Component [Descriptive Name] (Optional)	SCREEN PRINTER AND BAKE	ETCH HOOD & DRYER	DEGREASER
A10	Base Year For Equipment Prices [Price Year]	1980	1980	1980
A11	Purchase Price ($ Per Component) [Purchase Cost]	10,000	7,500	7,000
A12	Anticipated Useful Life (Years) [Useful Life]	8	8	8
A13	[Salvage Value] ($ Per Component)	0	25	0
A14	[Removal and Installation Cost] ($/Component)	800	550	500

Note: The SAMIS III computer program also accounts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the [illegible] use 0.0, (1975, 6.0), DDB, and SL.

JPL 3037-S R 1[illegible]

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) PATRN-8

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A2064D	144	SQ. FT.	MFG. SPACE (TYPE A)
B3096D	2	PERSON/SHIFT	SEMICONDUCTOR ASSEMBLER
B3736D	0.05	PERSON/SHIFT	MAINT. MECHANIC II

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
C1032B	0.25	KWH	ELECTRICITY
C2128B	800	CU. FT.	VENTILATION
E65000D	8.33E-4	GAL.	RESIST WAX
E65500D	1.25E-2	GAL.	DICHLOROMETHANE SOLVENT
C1144D	0.20	CU. FT.	WATER, D.I.

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A28 [Yield]* (%)	A26 [Ideal Ratio]** Of Units Out/Units In	A27 Units Of A26***	A25 Product Name
AR-SUB-8	99.2	1.0	SUBSTRATE / SUBSTRATE	AR COATED SUBSTRATE

Prepared by R. A. PRYOR Date 2-18-81

* 100% minus percentage of required product lost.
** Assume 100% yield here
*** Examples: Modules/Cell or Cells/Wafer

REVERSE SIDE JPL 3037-S R 10/78

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

PROCESS DESCRIPTION

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr / Pasadena, Calif 91103

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMIS III computer program.

A1 Process [Referent] NICKEL-8

A2 [Descriptive Name] ELECTROLESS NICKEL PLATE

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] N-CELL-8

A4 Descriptive Name [Product Name] NICKEL PLATED SOLAR CELL

A5 Unit Of Measure [Product Units] CELL

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 49.7 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] 14 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] 0.958 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	NI PLATER	DRYER	REPLEN
A9a	Component [Descriptive Name] (Optional)	NICKEL PLATING HOOD	MICROWAVE DRYER	AUTO BATH REPLENISHMENT SYSTEM
A10	Base Year For Equipment Prices [Price Year]	1978	1980	1980
A11	Purchase Price ($ Per Component) [Purchase Cost]	83,260	500	5000
A12	Anticipated Useful Life (Years) [Useful Life]	8	8	8
A13	[Salvage Value] ($ Per Component)	4,163	25	250
A14	[Removal and Installation Cost] ($/Component)	1,500	50	400

Note: The SAMIS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 6.0), DDB, and SL.

JPL 3037-S R:

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) NICKEL-8

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A2064D	104	SQ. FT.	MFG SPACE (TYPE A)
B3736D	0.05	PERSON/SHIFT	MAINT. MECHANIC II
B3096D	1	PERSON/SHIFT	SEMICONDUCTOR ASSEMBLER

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
C1032B	0.117	KWH	ELECTRICITY
C2128B	800	CU. FT.	VENTILATION
C1144D	0.335	CU. FT.	WATER, D.I.
EM 1200D	1.32 E-2	GAL.	DILUTE HYDROFLUORIC ACID
EM 1300D	3.24 E-2	GAL.	ELECTROLESS NICKEL SOLUTION

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A28 [Yield]* (%)	A26 [Ideal Ratio]** Of Units Out/Units In	A27 Units Of A26***	A25 Product Name
P-SUB-8	99.4	1.0	CELL / SUBSTRATE	PATTERNED SUBSTRATE

Prepared by R. A. PRYOR Date 2-18-81

* 100% minus percentage of required product lost
** Assume 100% yield here
*** Examples: Modules/Cell or C..., ...

REVERSE SIDE JPL 3037-S R 10/78

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

PROCESS DESCRIPTION

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr. / Pasadena, Calif 91103

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMIS III computer program.

A1 Process [Referent] SINTER - 8

A2 [Descriptive Name] METAL SINTER

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] S- CELL - 8

A4 Descriptive Name [Product Name] SINTERED SOLAR CELL

A5 Unit Of Measure [Product Units] CELL

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 48.00 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] 30 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] 0.96 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	BLT-FRN		
A9a	Component [Descriptive Name] (Optional)	BELT FURNACE		
A10	Base Year For Equipment Prices [Price Year]	1980		
A11	Purchase Price ($ Per Component) [Purchase Cost]	60,000		
A12	Anticipated Useful Life (Years) [Useful Life]	8		
A13	[Salvage Value] ($ Per Component)	3,000		
A14	[Removal and Installation Cost] ($/Component)	1500		

Note: The SAMIS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMIS context use 0.0, (1975, 6.0), DDB, and SL.

JPL 3C37-S R1

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) SINTER - 8

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A2064 D	168	SQ. FT.	MFG. SPACE (TYPE A)
B7096 D	0.5	PERSON/SHIFT	SEMICONDUCTOR ASSEMBLER
B7736 D	0.1	PERSON/SHIFT	MAINT. MECHANIC II

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
C1032 B	0.25	KWH	ELECTRICITY
C2128 B	100	CU. FT.	VENTILATION
E1416 D	16.6	CU. FT.	NITROGEN

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A28 [Yield]* (%)	A26 [Ideal Ratio]** Of Units Out/Units In	A27 Units Of A26***	A25 Product Name
N-CELL-8	99.8	1.0	CELL / CELL	NI PLATED SOLAR CELL

Prepared by R. A. PRYOR Date 2-18-81

* 100% minus percentage of required product lost
** Assume 100% yield here
*** Examples: Modules/Cell or Cc

REVERSE SIDE JPL 3037-S R 10/78

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr / Pasadena, Calif 91103

PROCESS DESCRIPTION

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMIS III computer program.

A1 Process [Referent] COPPER-8

A2 [Descriptive Name] ELECTROLESS COPPER PLATE

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] C-CELL-8

A4 Descriptive Name [Product Name] COPPER PLATED SOLAR CELL WITH PROTECTIVE CAP

A5 Unit Of Measure [Product Units] CELL

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 24.85 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] 101 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] 0.94 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS (Machine Description)

A9	Component [Referent]	CUPLATER	DRYER	REPLEN
A9a	Component [Descriptive Name] (Optional)	COPPER PLATING HOOD	MICROWAVE DRYER	AUTO BATH REPLENISHMENT SYSTEM
A10	Base Year For Equipment Prices [Price Year]	1980	1980	1980
A11	Purchase Price ($ Per Component) [Purchase Cost]	90,000	500	10,000
A12	Anticipated Useful Life (Years) [Useful Life]	8	8	8
A13	[Salvage Value] ($ Per Component)	4,500	25	500
A14	[Removal and Installation Cost] ($/Component)	1,500	50	400

Note: The SAMIS III computer program also permits for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context use 0.0, (1975, 6.0), DDB, and SL.

JPL 3037-S R1

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) COPPER-8

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A2064D	156	SQ. FT.	MFG. SPACE (TYPE A)
B7776D	6 E-2	PERSON/SHIFT	MAINT. MECHANIC II
B3096 D	0.5	PERSON/SHIFT	SEMICONDUCTOR ASSEMBLER

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
C1032B	0.35	KWH	ELECTRICITY
C2128B	800	CU. FT.	VENTILATION
C1144D	0.535	CU. FT.	WATER, D.I.
E62100D	2.21 E-2	GAL.	ELECTROLESS COPPER SOLUTION
E62200D	6.6 E-3	GAL.	IMMERSION TIN SOLUTION

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A28 [Yield]* (%)	A26 [Ideal Ratio]** Of Units Out/Units In	A27 Units Of A26***	A25 Product Name
S-CELL-8	99.4	1.0	CELL / CELL	SINTERED SOLAR CELL

Prepared by R. A. PRYOR Date 2-18-81

* 100% minus percentage of required product lost
** Assume 100% yield here
*** Examples: Modules/Cell or Cells/Wafer

ORIGINAL PAGE IS OF POOR QUALITY

REVERSE SIDE JPL 3037-S R 10/78

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr / Pasadena, Calif 91103

PROCESS DESCRIPTION

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMIS III computer program.

A1 Process [Referent] CELTST-8

A2 [Descriptive Name] ELECTRICAL TEST OF SOLAR CELLS

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] T-CELL-8

A4 Descriptive Name [Product Name] TESTED SOLAR CELL

A5 Unit Of Measure [Product Units] CELL

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 18.8 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] 0.15 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] 0.95 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	CTESTER		
A9a	Component [Descriptive Name] (Optional)	SOLAR CELL TESTER		
A10	Base Year For Equipment Prices [Price Year]	1980		
A11	Purchase Price ($ Per Component) [Purchase Cost]	46,000		
A12	Anticipated Useful Life (Years) [Useful Life]	8		
A13	[Salvage Value] ($ Per Component)	2,300		
A14	[Removal and Installation Cost] ($/Component)	400		

Note: The SAMIS III computer program also prompts for the [payment float interest], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context use 0.0, (1975, 6.0), DDB, and SL.

ORIGINAL PAGE IS OF POOR QUALITY

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) CEL TST - 8

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
(Facilities and Personnel Requirements)

A16 Catalog Number (Expense Item Referent)	A18 Amount Required Per Machine (Per Shift) (Amount per Machine)	A19 Units	A17 Requirement Description
A2664D	60	SQ. FT.	MFG. SPACE (TYPE A)
B3096D	0.667	PERSON/SHIFT	SEMICONDUCTOR ASSEMBLER
B3688D	5E-2.	PERSON/SHIFT	ELECTRONICS MAINT. MAN

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
(Byproduct Outputs) and (Utilities and Commodities Requirements)

A20 Catalog Number (Expense Item Referent)	A22 Amount Required Per Machine Per Minute (Amount per Cycle)	A23 Units	A21 Requirement Description
C1032B	2.5E-2	KWH	ELECTRICITY

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED (Required Products)

A24 (Product Reference)	A28 (Yield)* (%)	A26 (Ideal Ratio)** Of Units Out/Units In	A27 Units Of A26***	A25 Product Name
C-CELL-8	94.0	1.0	CELL/CELL	CU PLATED SOLAR CELL
			/	
			/	

Prepared by R.A. PRYOR Date 7-23-80

* 100% minus percentage of required product lost

** A[illegible] 100 [illegible]

*** Examples: Modules/Cell or Cell/Wafer.

REVERSE SIDE JPL 3037-S R 10/78

FORMAT A SET III

FOR

5 MIL THICK SLICES

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr / Pasadena, Calif 91103

PROCESS DESCRIPTION

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMIS III computer program.

A1 Process [Referent] SLICE-5

A2 [Descriptive Name] SLICING OF INGOTS TO 5 MIL WAFERS USING MULTIPLE WIRE SAW

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] WAFER-5

A4 Descriptive Name [Product Name] THREE INCH DIAMETER, 5 MIL THICK WAFER

A5 Unit Of Measure [Product Units] SQUARE METER

PART 2 – PROCESS CHARACTERISTICS

A6	[Output Rate] (Not Thruput)	5.18 E-3	Units (given on line A5) Per Operating Minute
A7	Average Time at Station [Processing Time]	220	Calendar Minutes (Used only to compute in-process inventory)
A8	Machine "Up" Time Fraction [Usage Fraction]	0.90	Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	SAW		
A9a	Component [Descriptive Name] (Optional)	WIRE SAW		
A10	Base Year For Equipment Prices [Price Year]	1977		
A11	Purchase Price ($ Per Component) [Purchase Cost]	30,000		
A12	Anticipated Useful Life (Years) [Useful Life]	7		
A13	[Salvage Value] ($ Per Component)	0		
A14	[Removal and Installation Cost] ($/Component)	3,000		

Note. The SAMIS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 6.0), DDB, and SL.

JPL 3037-S R1[illegible]

Format A: Process Description (Continued)

A15 **Process Referent (From Page 1 Line A1)** SLICE-5

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A2064D	40	SQ. FT.	MFG. SPACE (TYPE A)
B3096D	0.1	PERSON/SHIFT	SEMICONDUCTOR ASSEMBLER
B3736D	.48	PERSON/SHIFT	MAINT. MECHANIC II

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
C1032B	0.0083	KWH	ELECTRICITY
C1016B	0.134	CU. FT.	DOMESTIC WATER
E61000D	8.89	UNIT	SAW SUPPLIES

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A28 [Yield]* (%)	A26 [Ideal Ratio]** Of Units Out/Units In	A27 Units Of A26***	A25 Product Name
INGOT	80.0	1.313	SQ. M / KG.	THREE IN. DIA. SILICON INGOT

Prepared by R. A. PRYOR **Date** 7-23-80

* 100% minus percentage of required product lost.
** As[illegible] 100% yield [illegible]
*** Examples: Modules/Cell or Cells/Wafer.

REVERSE SIDE JPL 3037-S R 10/78

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

PROCESS DESCRIPTION

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr / Pasadena, Calif 91103

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMIS III computer program.

A1 Process [Referent] TEXETH-5

A2 [Descriptive Name] TEXTURE ETCH AND PRE-ETCH

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] TEXSUB-5

A4 Descriptive Name [Product Name] TEXTURE ETCHED SUBSTRATE

A5 Unit Of Measure [Product Units] SUBSTRATE

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 52.8 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] 90 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] 0.93 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	TETCHER		
A9a	Component [Descriptive Name] (Optional)	TEXTURE ETCHING HOOD		
A10	Base Year For Equipment Prices [Price Year]	1978		
A11	Purchase Price ($ Per Component) [Purchase Cost]	100,000		
A12	Anticipated Useful Life (Years) [Useful Life]	8		
A13	[Salvage Value] ($ Per Component)	5,000		
A14	[Removal and Installation Cost] ($/Component)	1,500		

Note: The SAMIS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS cost test use 0.0, (1975, 6.0), DDB, and SL.

JPL 3037-S R

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) TEXETH-5

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
(Facilities and Personnel Requirements)

A16 Catalog Number (Expense Item Referent)	A18 Amount Required Per Machine (Per Shift) (Amount per Machine)	A19 Units	A17 Requirement Description
A2064 D	120	SQ. FT.	MFG. SPACE (TYPE A)
B7096 D	0.5	PERSON/SHIFT	SEMICONDUCTOR ASSEMBLER
B3736 D	0.05	PERSON/SHIFT	MAINT. MECHANIC II

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
(Byproduct Outputs) and (Utilities and Commodities Requirements)

A20 Catalog Number (Expense Item Referent)	A22 Amount Required Per Machine Per Minute (Amount per Cycle)	A23 Units	A21 Requirement Description
C1032 B	0.05	KWH	ELECTRICITY
C2128 B	1000	CU. FT.	VENTILATION
C1144 D	0.832	CU. FT.	WATER, D.I.
E61360 D	6.6 E-2	KG	POTASSIUM HYDROXIDE
E1352 D	0.112	GAL	ISOPROPYL ALCOHOL
E1600 D	0.14	LB	SODIUM HYDROXIDE

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED (Required Products)

A24 (Product Reference)	A28 (Yield)* (%)	A26 (Ideal Ratio)** Of Units Out/Units In	A27 Units Of A26***	A25 Product Name
WAFER-5	99.0	2.193 E 2	SUBSTRATE / SQ. M.	FIVE MIL WAFER

Prepared by R. A. PRYOR Date 2-18-81

* 100% minus percentage of required product lost.
** Assume 100% yield here
*** Examples: Modules/Cell or Cells/...

REVERSE SIDE JPL 3037-S R 10/78

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

PROCESS DESCRIPTION

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr / Pasadena, Calif 91103

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMIS III computer program.

A1 Process [Referent] ION - 5

A2 [Descriptive Name] ION IMPLANT, N AND P TYPE

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] I-SUB-5

A4 Descriptive Name [Product Name] IMPLANTED SUBSTRATE

A5 Unit Of Measure [Product Units] SUBSTRATE

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 3.323 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] 7.5 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] 0.85 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	IMPLANTER		
A9a	Component [Descriptive Name] (Optional)	EXTRION ION IMPLANTER		
A10	Base Year For Equipment Prices [Price Year]	1980		
A11	Purchase Price ($ Per Component) [Purchase Cost]	486,000		
A12	Anticipated Useful Life (Years) [Useful Life]	8		
A13	[Salvage Value] ($ Per Component)	10,000		
A14	[Removal and Installation Cost] ($/Component)	4,000		

Note: The SAMIS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context use 0.0, (1975, 6.0), DDB, and SL.

JPL 3037-S R1

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) 10N-5

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A2064D	200	SQ. FT.	MFG. SPACE (TYPE A)
B3096 D	1	PERSON/SHIFT	SEMICONDUCTOR ASSEMBLER
B3736 D	0.15	PERSON/SHIFT	MAINT. MECHANIC II

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
C1032 B	0.42	KWH	ELECTRICITY
C2128B	1200	CU. FT.	VENTILATION
E61460 D	7.03 E-6	CU. FT.	PHOSPHINE
E61124 D	1.23 E-5	CU. FT.	BORON TRIFLUORIDE
C1016 B	2.01	CU. FT.	DOMESTIC WATER

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A28 [Yield]* (%)	A26 [Ideal Ratio]** Of Units Out/Units In	A27 Units Of A26***	A25 Product Name
TEXSUB-5	99.6	1.0	SUBSTRATE/SUBSTRATE	TEXTURE ETCHED SUBSTRATE

Prepared by R.A. PRYOR Date 2-18-81

* 100% minus percentage of required product lost
** Assume 100% yield here
*** Examples: Modules/Cell or Cells/Wafer

REVERSE SIDE JPL 3037-S R 10/78

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr. / Pasadena, Calif. 91103

PROCESS DESCRIPTION

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMIS III computer program.

A1 Process [Referent] DRIVE-5

A2 [Descriptive Name] DRIVE-IN DOPING REDISTRIBUTION OF IMPLANTED LAYERS

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] D-SUB-5

A4 Descriptive Name [Product Name] DOPED SUBSTRATE

A5 Unit Of Measure [Product Units] SUBSTRATE

PART 2 – PROCESS CHARACTERISTICS

A6	[Output Rate] (Not Thruput)	95.9	Units (given on line A5) Per Operating Minute
A7	Average Time at Station [Processing Time]	30	Calendar Minutes (Used only to compute in-process inventory)
A8	Machine "Up" Time Fraction [Usage Fraction]	0.96	Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS (Machine Description)

A9	Component [Referent]	BLT-FCE		
A9a	Component [Descriptive Name] (Optional)	BELT FURNACE		
A10	Base Year For Equipment Prices [Price Year]	1980		
A11	Purchase Price ($ Per Component) [Purchase Cost]	80000		
A12	Anticipated Useful Life (Years) [Useful Life]	8		
A13	[Salvage Value] ($ Per Component)	4,000		
A14	[Removal and Installation Cost] ($/Component)	1,500		

Note: The SAMIS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the USA SAMICS context use 0.0, (1975, 6.0), DDB, and SL.

JPL 3037-S R1

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) DRIVE-5

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A2064D	168	SQ. FT.	MFG. SPACE (TYPE A)
B3096D	0.5	PERSON/SHIFT	SEMICONDUCTOR ASSEMBLER
B3736D	0.1	PERSON/SHIFT	MAINT. MECHANIC II

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
C1032B	0.25	KWH	ELECTRICITY
C2128B	100	CU. FT.	VENTILATION
E1416D	16.6	CU. FT.	NITROGEN

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A28 [Yield]* (%)	A26 [Ideal Ratio]** Of Units Out/Units In	A27 Units Of A26***	A25 Product Name
I-SUB-5	99.3	1.0	SUBSTRATE/SUBSTRATE	IMPLANTED SUBSTRATE

Prepared by R. A. PRYOR Date 2-18-81

* 100% minus percentage of required product lost

** Assume 100 [illegible] here

*** Examples: Modules/Cell or Cells/[illegible]

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SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

PROCESS DESCRIPTION

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr / Pasadena, Calif 91103

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMIS III computer program.

A1 Process [Referent] SI3N4-5

A2 [Descriptive Name] SILICON NITRIDE DEPOSITION

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] AR-SUB-5

A4 Descriptive Name [Product Name] ANTIREFLECTION LAYER DEPOSITED ON SUBSTRATE

A5 Unit Of Measure [Product Units] SUBSTRATE

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 16.52 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] 60 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] 0.88 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	LPCVD		
A9a	Component [Descriptive Name] (Optional)	4-TUBE LPCVD FURNACE		
A10	Base Year For Equipment Prices [Price Year]	1980		
A11	Purchase Price ($ Per Component) [Purchase Cost]	160,000		
A12	Anticipated Useful Life (Years) [Useful Life]	8		
A13	[Salvage Value] ($ Per Component)	8,000		
A14	[Removal and Installation Cost] ($/Component)	1,500		

Note: The SAMIS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context use 0.0, (1975, 6.0), DDB, and SL.

JPL 3037-S R1

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) SI3N4-5

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A2064D	140	SQ.FT.	MFG. SPACE (TY - A)
B3096 D	0.5	PERSON/SHIFT	SEMICONDUCTOR ASSEMBLER
B3776 D	0.1	PERSON/SHIFT	MAINT. MECHANIC II

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
C1032B	1.166	KWH	ELECTRICITY
C2128B	65	CU. FT.	VENTILATION
E1108 D	5.95 E-3	CU. FT.	AMMONIA GAS
EM 1210 D	2.824 E-3	CU. FT.	DICHLOROSILANE
E1520 D	1.524 E-2	DOLLARS	QUARTZ
E1608 D	6.095 E-3	DOLLARS	SPARE PARTS
E1416 D	7.766 E-2	CU. FT.	NITROGEN

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A28 [Yield]* (%)	A26 [Ideal Ratio]** Of Units Out/Units In	A27 Units Of A26***	A25 Product Name
D-SUB-5	99.1	1.0	SUBSTRATE/SUBSTRATE	DOPED SUBSTRATE
			/	
			/	

Prepared by R. A. PRYOR Date 2-18-81

* 100% minus percentage of required product loss

** A [illegible]

*** Examples [illegible]

REVERSE SIDE JPL 3037-S R 10/7[illegible]

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

PROCESS DESCRIPTION

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove D / Pasadena, Calif 91103

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMIS III computer program.

A1	Process [Referent]	PATRN-5
A2	[Descriptive Name]	SCREENED WAX MASK PATTERN

PART 1 – PRODUCT DESCRIPTION

A3	[Product Referent]	P-SUB-5
A4	Descriptive Name [Product Name]	PATTERNED SUBSTRATE
A5	Unit Of Measure [Product Units]	SUBSTRATE

PART 2 – PROCESS CHARACTERISTICS

A6	[Output Rate] (Not Thruput)	4.12	Units (given on line A5) Per Operating Minute
A7	Average Time at Station [Processing Time]	30	Calendar Minutes (Used only to compute in-process inventory)
A8	Machine "Up" Time Fraction [Usage Fraction]	0.94	Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	SCREENER	ETCHER	DEGRS
A9a	Component [Descriptive Name] (Optional)	SCREEN PRINTER AND BAKE	ETCH HOOD & DRYER	DEGREASER
A10	Base Year For Equipment Prices [Price Year]	1980	1980	1980
A11	Purchase Price ($ Per Component) [Purchase Cost]	10,000	7,500	7,000
A12	Anticipated Useful Life (Years) [Useful Life]	8	8	8
A13	[Salvage Value] ($ Per Component)	0	25	0
A14	[Removal and Installation Cost] ($/Component)	800	550	500

Note. The SAMIS III computer program [illegible] for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [illegible] book depreciation method]. In the [illegible] use 0.0, (1975, 6.0), DDB, and SL.

Format A. Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) PATRN-5

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
(Facilities and Personnel Requirements)

A16 Catalog Number (Expense Item Referent)	A18 Amount Required Per Machine (Per Shift) (Amount per Machine)	A19 Units	A17 Requirement Description
A2064D	144	SQ. FT.	MFG. SPACE (TYPE A)
B3096D	2	PERSON/SHIFT	SEMICONDUCTOR ASSEMBLER
B3736D	0.05	PERSON/SHIFT	MAINT. MECHANIC II

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
(Byproduct Outputs) and (Utilities and Commodities Requirements)

A20 Catalog Number (Expense Item Referent)	A22 Amount Required Per Machine Per Minute (Amount per Cycle)	A23 Units	A21 Requirement Description
C1032B	0.25	KWH	ELECTRICITY
C2128B	800	CU. FT.	VENTILATION
E65000D	2.33E-4	GAL.	RESIST WAX
E65500D	1.25E-2	GAL.	DICHLOROMETHANE SOLVENT
C1144D	0.20	CU. FT.	WATER, D.I.

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED (Required Products)

A24 (Product Reference)	A28 (Yield)* (%)	A26 (Ideal Ratio)** Of Units Out/Units In	A27 Units Of A26***	A25 Product Name
AR-SUB-5	98.9	1.0	SUBSTRATE / SUBSTRATE	AR COATED SUBSTRATE

Prepared by R.A. PRYOR Date 2-18-81

* 100% minus percentage of required product lost
** Assume 100 ... here
*** Examples. Modules/Cell or ...

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REVERSE SIDE JPL 3037-S R 10/76

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr / Pasadena, Calif 91103

PROCESS DESCRIPTION

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMIS III computer program.

A1 Process [Referent] NICKEL-5

A2 [Descriptive Name] ELECTROLESS NICKEL PLATE

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] N-CELL-5

A4 Descriptive Name [Product Name] NICKEL PLATED SOLAR CELL

A5 Unit Of Measure [Product Units] CELL

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 49.6 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] 14 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] 0.958 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	NIPLATER	DRYER	REPLEN
A9a	Component [Descriptive Name] (Optional)	NICKEL PLATING HOOD	MICROWAVE DRYER	AUTO BATH REPLENISHMENT SYSTEM
A10	Base Year For Equipment Prices [Price Year]	1978	1980	1980
A11	Purchase Price ($ Per Component) [Purchase Cost]	83,260	500	5000
A12	Anticipated Useful Life (Years) [Useful Life]	8	8	8
A13	[Salvage Value] ($ Per Component)	4,163	25	250
A14	[Removal and Installation Cost] ($/Component)	1,500	50	400

Note: The SAMIS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method] and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 6.0), DDB, and St...

JPL 3037-S R1:

Format A. Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) NICKEL-5

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A2064D	104	SQ. FT.	MFG SPACE (TYPE A)
B3736D	0.05	PERSON/SHIFT	MAINT. MECHANIC II
B3096D	1	PERSON/SHIFT	SEMICONDUCTOR ASSEMBLER

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
C1032B	0.117	KWH	ELECTRICITY
C2128B	800	CU. FT.	VENTILATION
C1144D	0.335	CU. FT.	WATER, D.I.
EM1200D	1.32 E-2	GAL.	DILUTE HYDROFLUORIC ACID
EM1300D	3.24 E-2	GAL.	ELECTROLESS NICKEL SOLUTION

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A28 [Yield]* (%)	A26 [Ideal Ratio]** Of Units Out/Units In	A27 Units Of A26***	A25 Product Name
P-SUB-5	99.2	1.0	CELL/SUBSTRATE	PATTERNED SUBSTRATE

Prepared by R. A. Pryor Date 2-18-81

* 100% minus percentage of required product lost

** Assume 100% yield here

*** Examples: Modules/Cell or C...

REVERSE SIDE JPL 3037-S R 10/76

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr / Pasadena, Calif 91103

PROCESS DESCRIPTION

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMIS III computer program.

A1 Process [Referent] SINTER - 5

A2 [Descriptive Name] METAL SINTER

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] S- CELL - 5

A4 Descriptive Name [Product Name] SINTERED SOLAR CELL

A5 Unit Of Measure [Product Units] CELL

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 47.95 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] 30 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] 0.96 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	BLT-FRN		
A9a	Component [Descriptive Name] (Optional)	BELT FURNACE		
A10	Base Year For Equipment Prices [Price Year]	1980		
A11	Purchase Price ($ Per Component) [Purchase Cost]	60,000		
A12	Anticipated Useful Life (Years) [Useful Life]	8		
A13	[Salvage Value] ($ Per Component)	3,000		
A14	[Removal and Installation Cost] ($/Component)	1500		

Note: The SAMIS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMIS III context, use 0.0, (1975, 6.0), DDB, and SL.

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Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) SINTER-5

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A2064 D	168	SQ. FT.	MFG. SPACE (TYPE A)
B7096 D	0.5	PERSON/SHIFT	SEMICONDUCTOR ASSEMBLER
B7736 D	0.1	PERSON/SHIFT	MAINT. MECHANIC II

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
C1032B	0.25	KWH	ELECTRICITY
C2128B	100	CU. FT.	VENTILATION
E 1416 D	16.6	CU. FT.	NITROGEN

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A28 [Yield]* (%)	A26 [Ideal Ratio]** Of Units Out/Units In	A27 Units Of A26***	A25 Product Name
N-CELL-5	99.7	1.0	CELL / CELL	NI PLATED SOLAR CELL
			/	
			/	

Prepared by R. A. PRYOR Date 2-18-81

* 100% minus percentage of required product lost
** Assume 100% yield here
*** Examples: Modules/Cell or Cc[illegible]

REVERSE SIDE JPL 3037-S R 10/78

C-3

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr. / Pasadena, Calif. 91103

PROCESS DESCRIPTION

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMIS III computer program.

A1 Process [Referent] COPPER-5

A2 [Descriptive Name] ELECTROLESS COPPER PLATE

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] C-CELL-5

A4 Descriptive Name [Product Name] COPPER PLATED SOLAR CELL WITH PROTECTIVE CAP

A5 Unit Of Measure [Product Units] CELL

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 24.80 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] 101 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] 0.94 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	CUPLATER	DRYER	REPLEN
A9a	Component [Descriptive Name] (Optional)	COPPER PLATING HOOD	MICROWAVE DRYER	AUTO BATH REPLENISHMENT SYSTEM
A10	Base Year For Equipment Prices [Price Year]	1980	1980	1980
A11	Purchase Price ($ Per Component) [Purchase Cost]	90,000	500	10,000
A12	Anticipated Useful Life (Years) [Useful Life]	8	8	8
A13	[Salvage Value] ($ Per Component)	4,500	25	500
A14	[Removal and Installation Cost] ($/Component)	1,500	50	400

Note: The SAMIS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 6.0), DDB, and SL.

JPL 3037-5 R10

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) COPPER - S

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A2064D	156	SQ. FT.	MFG. SPACE (TYPE A)
B3736D	6 E-2	PERSON/SHIFT	MAINT. MECHANIC II
B3096D	0.5	PERSON/SHIFT	SEMICONDUCTOR ASSEMBLER

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
C1032B	0.35	KWH	ELECTRICITY
C2128B	800	CU. FT.	VENTILATION
C1144D	0.535	CU. FT.	WATER, D.I.
E62100D	2.21 E-2	GAL.	ELECTROLESS COPPER SOLUTION
E62200D	6.6 E-3	GAL.	IMMERSION TIN SOLUTION

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A28 [Yield]* (%)	A26 [Ideal Ratio]** Of Units Out/Units In	A27 Units Of A26***	A25 Product Name
S-CELL-S	99.2	1.0	CELL / CELL	SINTERED SOLAR CELL

Prepared by R. A. PRYOR **Date** 2-18-81

* 100 [illegible] minus percentage of required product lost
** Assume 100 [illegible] yield here
*** Examples: Modules/Cell or Cells/[illegible]

REVERSE SIDE JPL 3037-S R 10/78

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

PROCESS DESCRIPTION

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr / Pasadena, Calif 91103

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMIS III computer program.

A1 Process [Referent] CELTST-5

A2 [Descriptive Name] ELECTRICAL TEST OF SOLAR CELLS

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] T-CELL-5

A4 Descriptive Name [Product Name] TESTED SOLAR CELL

A5 Unit Of Measure [Product Units] CELL

PART 2 – PROCESS CHARACTERISTICS

A6	[Output Rate] (Not Thruput)	18.8	Units (given on line A5) Per Operating Minute
A7	Average Time at Station [Processing Time]	0.15	Calendar Minutes (Used only to compute in-process inventory)
A8	Machine "Up" Time Fraction [Usage Fraction]	0.95	Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	CTESTER		
A9a	Component [Descriptive Name] (Optional)	SOLAR CELL TESTER		
A10	Base Year For Equipment Prices [Price Year]	1980		
A11	Purchase Price ($ Per Component) [Purchase Cost]	46,000		
A12	Anticipated Useful Life (Years) [Useful Life]	8		
A13	[Salvage Value] ($ Per Component)	2,300		
A14	[Removal and Installation Cost] ($/Component)	400		

Note: The SAMIS III computer program also prompts for the [payment float interest], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 6.0), DDB, and SL.

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Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) CEL TST - 5

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)

[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A2664D	60	SQ. FT.	MFG. SPACE (TYPE A)
B3096D	0.667	PERSON/SHIFT	SEMICONDUCTOR ASSEMBLER
B3688D	5E-2	PERSON/SHIFT	ELECTRONICS MAINT. MAN

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE

[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
C1032B	2.5E-2	KWH	ELECTRICITY

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A28 [Yield]* (%)	A26 [Ideal Ratio]** Of Units Out/Units In	A27 Units Of A26***	A25 Product Name
C-CELL-5	94.0	1.0	CELL/CELL	CU PLATED SOLAR CELL

Prepared by R. A. PRYOR Date 7-23-80

* 100% minus percentage of required product lost

** Assume 100% yield [illegible]

*** Examples. Modules/Cell or Cell/Wafer.

REVERSE SIDE JPL 3037-S R 10/78

EXAMPLE CALCULATIONS
FOR DATA OF
SAMICS FORMAT A SET II
(8 MIL THICK SLICES)

SLICE-8

Assumptions:

Slice thickness	.0080 in.
Kerf	.0078 in.
Ingot size	3 in. dia., 4 in. long
Saw set-up time	40 min.
Cutting time	180 min.
Saw cost	$30,000 in 1977
Operator requirement	0.1 person/machine
Maintenance man requirement	0.48 person/machine
Raw water usage	1 gal./min.
Electricity	500 W/machine
Proprietary saw supplies	$.0724/min.
Slicing yield	85%

A7: Cycle time

Cycle time = set up + cutting

= 40 min. + 180 min.

= 220 min.

A6: Output rate

$$\frac{4.0 \text{ in}}{(.0080 + .0078) \text{ in/waf}} \times \frac{1}{220 \text{ min}} = 1.151 \text{ waf/min}$$

3 in. dia. wafer → 45.6 cm^2

$$\frac{1.151 \text{ waf}}{\text{min}} \times \frac{45.6 \text{ cm}^2}{\text{waf}} \times \frac{1 \text{ m}^2}{10^4 \text{cm}^2} = 5.25 \times 10^{-3} \text{ m}^2/\text{min.}$$

$$\frac{5.25 \times 10^{-3} \text{m}^2}{\text{min}} \times 0.850 \text{ yield} = 4.46 \times 10^{-3} \text{ m}^2/\text{min.}$$

SLICE-8 (Continued)

A22: Direct requirements per min.

Electricity: 500 W/machine = 0.5 KW/machine

$$0.5 \text{ KW} \times 220 \text{ min} \times \frac{1 \text{ hr}}{60 \text{ min}} \times \frac{1}{220 \text{ min/cycle}} = 8.3 \times 10^{-3} \text{ KWH/min.}$$

Domestic water: 1 gal/min.

$$\frac{1 \text{ gal}}{\text{min}} \times \frac{0.1337 \text{ ft}^3}{\text{gal}} = 0.134 \text{ ft}^3\text{/min.}$$

Proprietary saw supplies (abrasive, wire, etc.): \$.0724/min.

$$\frac{\$.0724}{\text{min}} = \frac{7.24 \text{ units}}{\text{min}} \times \frac{\$.01}{\text{unit}}$$

A26: Units out/units in

$$\frac{45.6 \text{ cm}^2 \text{ output}}{45.6 \text{ cm}^2 \times (.0080 + .0078) \text{ in} \times \frac{2.54 \text{ cm}}{\text{in}} \times \frac{2.33 \text{ g}}{\text{cm}^3} \text{ input}} = 10.69 \text{ cm}^2/\text{g}$$

$$\frac{10.69 \text{ cm}^2}{\text{g}} \times \frac{1 \text{ m}^2}{10^4 \text{ cm}^2} \times \frac{10^3 \text{ g}}{1 \text{ Kg}} = \frac{1.069 \text{ m}^2}{\text{Kg}}$$

II/II III-8

Assumptions: (Proprietary Process)

Texture etch system including multi-tank chemical hood with microprocessor controlled walking beam system and microwave drying end station. Wet chemical tanks include sodium hydroxide etching, texture etching, and rinsing stations.

A6: Output rate

Carriers containing 50 wafers each will be transported through the system at a rate of 3200 wafers per hour.

$$\frac{3200 \text{ waf}}{\text{hr.}} \times \frac{1 \text{ hr}}{60 \text{ min.}} \text{ X } 0.992 \text{ yield} = 52.9 \text{ waf/min}$$

A7: Cycle time

Average processing time for a complete cycle is 90 minutes.

A18: Direct requirements per machine

Required floorspace is approximately 200 ft^2 and one operator can run two automated stations.

A22: Direct requirements per minute

Electricity:

Electrical demand is 3 KW.

$$3 \text{ KW X } \frac{1 \text{ hr}}{60 \text{ min}} = 0.05 \text{ KWH/min.}$$

D.I. water:

Deionized water demand is 23.5 ℓ/min.

$$\frac{23.5 \text{ ℓ}}{\text{min}} \text{ X } \frac{1 \text{ gal}}{3.785\text{ℓ}} \text{ X } \frac{.134 \text{ ft}^3}{\text{gal.}} = 0.832 \text{ ft}^3\text{/min.}$$

TEXETH-8

Etch baths:

Formula is proprietary.

Usage rates are

Sodium hydroxide	0.14 lb/min
Potassium hydroxide	0.066 kg/min
Isopropyl alcohol	0.112 gal/min

A26: Units out/units in

$$\frac{1 \text{ substrate}}{45.6 \text{ cm}^2} \times \frac{10^4 \text{ cm}^2}{\text{m}^2} = 219.3 \text{ substrates/m}^2$$

Assumptions:

Extrion Pre-Dep Ion Implanter Model 80-10 with options including auto-load, data-log, low energy conversion, and service contract. The 1980 price quotation is \$395,000 base plus \$91,000 for the options for a total of \$486,000.

A6: Output rate

At doses of 2×10^{15} cm^{-2} and below, maximum throughput is 400 wafers per hour (3 inch or 100 mm diameter). In this step both front and back of wafer are implanted in separate operations. This reduces the effective throughput to 200 wafers/hr.

$$\frac{200 \text{ waf}}{\text{hr}} \times \frac{1 \text{ hr}}{60 \text{ min}} \times .998 \text{ yield} = 3.33 \text{ waf/min}$$

A7: Cycle time

Batch size for 3 in. or 100 mm wafers is 25.

$$\frac{1 \text{ hr}}{200 \text{ waf}} \times \frac{60 \text{ min}}{1 \text{ hr}} \times \frac{25 \text{ waf}}{1 \text{ batch}} = 7.5 \text{ min/batch}$$

A18: Direct requirements per machine

Floorspace:

Machine dimensions are 7.5 ft by 15.5 ft or 116.25 ft^2. Add to this workspace to obtain 200 ft^2 required.

A22: Direct requirements per minute

Electricity

Demand is estimated at one half the face-plate power of 50 kVA or 25 KW.

$$25 \text{ KW} \times \frac{1 \text{ hr}}{60 \text{ min}} = 0.42 \text{ KWH/min}$$

ION-8 (Continued)

Domestic Water:

Requirement is 15 gal/min

$$\frac{15\ \text{gal}}{\text{min}} \times \frac{0.1337\ \text{ft}^3}{\text{gal}} = 2.01\ \text{ft}^3/\text{min}$$

Phosphine:

Assume 5 mA beam current of 31P+

$5\ \text{mA} = 5 \times 10^{-3}$ coul/sec

$$\frac{5 \times 10^{-3}\ \text{coul}}{\text{sec}} \times \frac{1\ \text{on}}{1.602 \times 10^{-19}\ \text{coul}} \times \frac{1\ \text{molecule}}{(\text{EFF})\ \text{ions}}$$

$$\times \frac{1\ \text{g-mole}}{6.023 \times 10^{23}\ \text{molecules}} \times \frac{22.414\ \ell}{\text{g-mole}} \times \frac{60\ \text{sec}}{\text{min}}$$

$$\times \frac{1\ \text{ft}^3}{28.32\ \ell} = \frac{2.46 \times 10^{-6}\ \text{ft}^3/\text{min}}{(\text{EFF})}$$

where (EFF) is the ionization efficiency of obtaining 31P+ from PH_3 gas.

Assume (EFF) is 35%.

Then PH_3 usage is

$$\frac{2.46 \times 10^{-6}}{0.35}\ \text{ft}^3/\text{min} = 7.03 \times 10^{-6}\ \text{ft}^3/\text{min}.$$

Boron Trifluoride:

Assume 5 mA beam current of 11B+ and (EFF) value of 20%.

Then BF_3 usage is

$$\frac{2.46 \times 10^{-6}}{0.20}\ \text{ft}^3/\text{min} = 1.23 \times 10^{-5}\ \text{ft}^3/\text{min}.$$

DRIVE-8

Assumptions:

Watkins-Johnson belt furnace with input/output modifications at $45,000 plus quartz lining system at $20,000 plus automatic load/unload apparatus at $15,000. Total 1980 cost is $80,000.

A6: Output rate

Furnace belt speed is 10 in/min. providing 15 min. anneal at high temperature in 150 in. hot zone.

Carriers of 50 wafers each are placed on belt at about 5 3/16 in. intervals.

$$\frac{50 \text{ waf}}{5.18 \text{ in}} \times \frac{10 \text{ in}}{\text{min.}} \times .994 \text{ yield} = 96.0 \text{ waf/min}$$

A7: Cycle time

Overall travel distance on belt (load-hot zone-unload) is 300 in.

$$300 \text{ in} \times \frac{1 \text{ min}}{10 \text{ in}} = 30 \text{ min transport time}$$

A18: Direct requirements per machine

Floor space: Equipment dimensions are 3 ft by 28 ft = 84 ft^2 plus additional 84 ft^2 workspace. Total is 168 ft^2.

S13N4-8

Assumptions:

Low pressure chemical vapor deposition of silicon nitride uses a conventional hot wall furnace (such as Thermco) in a 4 tube cabinet. The system includes automatic digital temperature control with automatic temperature profiling using internal tube thermocouples. Each tube is microprocessor controlled. Closed loop gas flow control utilizing thermal mass flow controllers is employed. The vacuum system includes a capacitance manometer and vacuum throttle valve control, cryogenic trap, and a direct drive pump. Automatic boat loaders are used. Such a system costs $40,000 per tube in a 4-tube cabinet. (1980 dollars)

A6: Output rate

Using close loading (90 mil spacing), 250 wafers can be processed per run per tube. Hence, a 4-tube unit can handle 1000 wafers per run. Each run requires 60 min.

$$\frac{1000 \text{ wafers}}{\text{run}} \times \frac{1 \text{ run}}{60 \text{ min}} \times 0.992 \text{ yield} = 16.53 \text{ waf/min}$$

A7: Cycle time

Total cycle time per run is 60 min.

A18: Direct requirements per machine.

Operators:

One operator can run 8 furnace tubes.

$$\frac{1 \text{ operator}}{8 \text{ tubes}} \times \frac{4 \text{ tubes}}{\text{system}} = 0.5 \text{ operator/system}$$

SI3N4-8 (Continued)

A22: Direct requirements per minute

Electricity:

Electrical demand is 70 KW.

$$70 \text{ KW} \times \frac{1 \text{ hr}}{60 \text{ min}} = 1.166 \text{ KWH}$$

Dichlorosilane:

This gas is on for 20 min. out of 60 min cycle at flow of 60 cm^3/min per tube.

$$\frac{60 \text{ cm}^3}{\text{tube-min}} \times \frac{20 \text{ min}}{60 \text{ min}} \times \frac{3.53 \times 10^{-5} \text{ ft}^3}{\text{cm}^3} \times 4 \text{ tubes} = 2.824 \times 10^{-3} \text{ ft}^3\text{/min averag}$$

Ammonia:

This gas is on for 22 min. out of 60 min. cycle at flow of 115 cm^3/min per tube.

$$\frac{115 \text{ cm}^3}{\text{tube-min}} \times \frac{22 \text{ min}}{60 \text{ min}} \times \frac{3.53 \times 10^{-5} \text{ ft}^3}{\text{cm}^3} \times 4 \text{ tubes} = 5.95 \times 10^{-3} \text{ ft}^3\text{/min. averag}$$

Nitrogen;

This gas is on for purging for 10 min. out of 60 min. cycle at flow of 3.3 ℓ/min or 3300 cm^3/min. per tube.

$$\frac{3300 \text{ cm}^3}{\text{tube-min}} \times \frac{10 \text{ min}}{60 \text{ min}} \times \frac{3.53 \times 10^{-5} \text{ ft}^3}{\text{cm}^3} \times 4 \text{ tubes} = 7.766 \times 10^{-2} \text{ ft}^3\text{/min averag}$$

PATRN-8

Assumptions:

Forslund screen printer and I.R. belt drier at 1980 cost of \$10,000.

Exhausted chemical etch hood and microwave dryer at 1980 cost of \$7,500.

Ultrasonic degreaser at 1980 cost of \$7,000.

Output rate of 250 3 in. diameter wafers per hour.

Operator requirement of one screen operator, one etch and degrease operator.

A6: Output rate

$$250 \text{ waf/hr} \times \frac{1 \text{ hr}}{60 \text{ min}} \times 0.992 \text{ yield} = 4.13 \text{ waf/min}$$

A7: Cycle time per 25 wafer carrier

Screen print 25 wafers X 10 sec/waf = 250 sec → 5 min.

Bake → 5 min

Etch, rinse, dry → 15 min

Clean (degrease) → 5 min

Total = 30 min.

A18: Direct requirements per machine

Floorspace:

Screener	12 ft^2	Total = 144 ft^2
Belt Dryer	20 ft^2	
Hood	18 ft^2	
Dryer	12 ft^2	
Degreaser	18 ft^2	
Walkway	64 ft^2	

PATRN-8 (Continued)

A22: Direct requirements per minute

Resist wax:

Wax coverage = 5000 wafers per gal.

$$\frac{250 \text{ waf}}{\text{hr}} \times \frac{1 \text{ hr}}{60 \text{ min}} \times \frac{1 \text{ gal}}{5000 \text{ waf.}} = 8.33 \times 10^{-4} \text{ gal/min}$$

Solvent use:

$$\frac{30 \text{ gal}}{\text{week}} \times \frac{1 \text{ week}}{40 \text{ hr}} \times \frac{1 \text{ hr}}{60 \text{ min}} = 1.25 \times 10^{-2} \frac{\text{gal}}{\text{min}}$$

NICKEL-8

Assumptions:

Walking beam plating system (Fluorocarbon) quoted at \$83,260 in 1978.

Microwave dryer costing \$500 in 1980.

Automatic plating solution monitor and replenisher costing \$5000 in 1980.

Walking beam capacity of 2 - 50 wafer carriers per station

A6: Output rate

Maximum time at any walking beam position is 2 min.

$$\frac{2 \times 50 \text{ waf/position}}{2 \text{ min/position}} = 50 \text{ waf/min}$$

$$\frac{50 \text{ waf}}{\text{min}} \times 0.994 \text{ yield} = 49.7 \text{ waf/min}$$

A7: Cycle time:

12 min. time through walking beam stations (including load, HF etching and surface preparation, rinses, nickel plating, and unload)

2 min. dry time

14 min. total

A18: Direct requirements per machine

Floorspace:

Equipment dimensions = 13 ft X 4 ft = 52 ft^2

Double to account for work space = 104 ft^2 total

A22: Direct requirements per minute

Nickel plating solution:

One gal of nickel solution contains 21.1 g of Ni.

At 80% efficiency of Ni use, one gal can supply 16.9 g of Ni.

Coverage of wafer is 100% back and 8% front, or $45.6 + 3.6\ cm^2 = 49.2\ cm^2$

Thickness of deposit is 2500 Å

Density of Ni is 8.90 g/cm^3

Thus

$$\frac{8.90g}{cm^3} \times \frac{10^{-8}\ cm}{Å} \times \frac{49.2\ cm^2}{wafer} \times \frac{50\ wafer}{min} \times 2500Å \times \frac{1\ gal}{16.9\ g}$$

$$= 3.24 \times 10^{-2}\ gal/min.$$

D.I. Water:

Water usage is $2.5\ gal/min \times \frac{.1337\ ft^3}{gal} = .335\ ft^3/min$

Dilute HF solution usage;

Assume usage is by drag-out of 1 mℓ per wafer

$$\frac{50\ wafers}{min} \times \frac{1\ ml}{wafer} \times \frac{1ℓ}{1000\ ml} \times \frac{.2642\ gal}{ℓ} = \frac{1.32 \times 10^{-2}\ gal}{min}$$

Electricity:

Estimated electrical demand is 7.0 KW.

$$7.0\ kW \times \frac{1\ hr}{60\ min} = 0.117\ KWH/min$$

SINTER-8

Assumptions:

Watkins-Johnson belt furnace with input/output modifications at $45,000 in 1980 plus an automatic load/unload apparatus at $15,000 in 1980. Total is $60,000.

A6: Output rate

Furnace belt speed is 10 in/min providing 15 min. sinter in 150 in. hot zone. Carriers of 25 wafers each are placed on belt at 5.2 in. intervals.

$$\frac{25 \text{ wafers}}{5.2 \text{ in}} \times \frac{10 \text{ in}}{\text{min}} = 48.1 \text{ wafers/min}$$

$$\frac{48.1 \text{ wafers}}{\text{min}} \times 0.998 \text{ yeild} = 48.0 \text{ wafers/min}$$

A7: Cycle time

Overall travel distance on belt (load-hot zone-unload) is 300 in.

$$300 \text{ in.} \times \frac{1 \text{ min}}{10 \text{ in}} = 30 \text{ min. transport time}$$

A18: Direct requirements per machine

Floor space:

Equipment dimensions are 3 ft b 28 ft = 84 ft^2 plus additional 84 ft^2 workspace. Total is 168 ft^2.

COPPER-8

Assumptions:

Walking beam motion plating system estimated to cost \$90,000 in 1980.

Microwave dryer costing \$500 in 1980.

Automatic plating solution monitor an replenisher control system costing \$10,000 in 1980.

A6: Output rate

Each walking beam position has 12 carriers of 25 wafers each. Dwell time at any one position is at most 12 min.

$$\frac{12\ \text{carriers}}{\text{batch}} \times \frac{25\ \text{wafers}}{\text{carrier}} \times \frac{1\ \text{batch}}{12\ \text{min}} = 25\ \text{wafers/min}$$

$$\frac{25\ \text{wafers}}{\text{min}} \times 0.994\ \text{yield} = 24.85\ \text{wafers/min}$$

A7: Cycle Time

Desired copper thickness of 0.2 mil and plating rate of 0.2 mil/hr gives one hr. required plating time.

Copper plate	60 min	
Rinse	12 min	
Tin plate	5 min	
Rinse	12 min	
Dry	12 min	
Total	101 min	cycle time

A18: Direct requirements per machine

Floorspace:

Walking beam hood consists of load/unload areas, plating tanks, and rinse tanks which are 3 ft. wide and total 12 ft long. Overall hood dimensions are 4 ft by 15 ft, which is 60 ft^2. Chemical storage (plating solution

reservoir) is 3 ft by 6 ft for 18 ft^2. Total equipment area is 78 ft^2.

Double this to account for work space. Hence, 156 ft^2.

Maintenance man:

Downtime is 1.5 hr every 24 hr.

Thus, $\frac{1.5}{24}$ = 0.06 maintenance man needed.

A22: Direct requirements per minute

Electroless copper plating solution:

Copper solution replenishment can deliver 12 mil-ft^2/gal

Wafer coverage is 100% back and 8% front or 49.2 cm^2. Copper thickness is 0.2 mil.

Hence,

$$\frac{49.2\ cm^2}{wafer} \times \frac{1\ in^2}{(2.54\ cm)^2} \times \frac{1\ ft^2}{144\ in^2} \times 0.2\ mil$$

$$\times \frac{25\ waf}{min} \times \frac{1\ gal}{12\ mil\text{-}ft^2} = .0221\ gal/min$$

Immersion tin plating solution:

One gal. of tin solution can plate 200 ft^2 of surface.

Hence,

$$\frac{49.2\ cm^2}{wafer} \times \frac{1\ in^2}{(2.54\ cm)^2} \times \frac{1\ ft^2}{144 in^2} \times \frac{1\ gal}{200\ ft^2} \times \frac{25\ wafers}{min} = .0066\ gal/min$$

D.I. water:

2 gal/min. per rinse tank, 2 tanks, thus

$$\frac{4\ gal}{min} \times 0.1337\ ft^3/gal = 0.535\ ft^3/min$$

Electricity:

Estimated demand is 21 KW

$$21\ KW \times \frac{1\ Hr}{60\ min} = 0.35\ KWH/min.$$

CELTST-8

Assumptions:

A solar cell tester comprised of a transport system, a light source, a test stage, a table top computer control system, a power supply, and monitoring meters is estimated to cost $56,000 in 1980.

This test and sort system is 3 ft. wide by 10 ft. long.

A6: Output rate

Each cell test (current-voltage characterization) requires 3 sec.

$$\frac{60 \text{ sec}}{\text{min}} \times \frac{1 \text{ cell}}{3 \text{ sec}} \times 0.940 \text{ yield} = 18.8 \text{ cells/min.}$$

The yield of 94% is assumed to be primarily electrical rejection rather than mechanical breakage.

A7: Cycle time

An additional 6 sec. is required for loading, unloading, and sorting each cell.

Total time at station is 6 + 3 = 9 sec

$$\frac{1 \text{ min}}{60 \text{ sec}} \times 9 \text{ sec} = 0.15 \text{ min}$$

A18: Direct requirements per machine

Floor space:

Floorspace requirement is twice the equipment space or 60 ft^2.

Operators:

It is assumed that 2 operators can run three such testers, one operator handling input substrates and the other removing output substrates.

$$\frac{2 \text{ operators}}{3 \text{ machines}} = 0.667 \text{ operator/machine}$$

CLLIST-8 (Continued)

Maintenance:

Up time of 95% or down time of 5% means that 0.05 maintenance mechanic is needed.

A22: Direct requirements per minute

Electricity:

Demand is 1.5 KW.

$$1.5 \text{ KW} \times \frac{1 \text{ hr}}{60 \text{ min}} = .025 \text{ KWH/min}$$